EFFECTS OF PROACTIVE AND RETROACTIVE AUGMENTED INFORMTAION ON PHYSIOLOGICAL RESPONSES IN LEARNING A NOVEL MOTOR SKILL

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ABSTRACT

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Previous research has demonstrated superior learning by participants presented with augmented task information retroactively versus proactively (Patterson & Lee, 2008; 2010). Theoretical explanations of these findings are related to the cognitive effort invested by participants during motor skill acquisition. The present study extended previous research by utilizing the physiological index, power spectral analysis of heart rate variability, previously shown to be sensitive to the degree of cognitive effort invested during the *performance* of a motor task (e.g., increase cognitive effort results in increased LF/HF ratio). Participants were required to learn 18 different key-pressing sequences. As expected, the proactive condition demonstrated superior RS during acquisition, with the retroactive condition demonstrating superior RS during retention. Measures of LF/HF ratio indicated the retroactive participants were investing significantly less cognitive effort in the retention period compared to the proactive participants ($p < .05$) as a function of learning.

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CHAPTER 1: REVIEW OF LITERATURE

1.1 INTRODUCTION

Our capacity to plan, perform, and learn new motor skills is essential for the successful execution of daily activities. A motor skill is a learned sequence of movements that requires voluntary body and/or extremity movement to achieve a goal (Magill, 2001). However, motor learning is the process of improving one's motor skills leading to a relatively permanent change in one's ability to perform a motor skill (Schmidt & Lee, 2011). The acquisition of new motor skills and the refinement of existing motor skills occurs on a continuous basis throughout one's life. The ability to measure and manipulate practice conditions to optimize performance and learning is critical for the enhancement and efficiency of training or retraining a wide variety of motor skills. The more that is known about how motor skills are performed, learned, and adapt to new demands, the better the guidance that can be provided to professionals attempting to design training (e.g. surgical skills or preparing a pilot for their first solo flight) and retraining programs (e.g. rehabilitation). Optimizing a learning condition involves careful manipulation of the practice context. Motor learning is enhanced when practice variables are manipulated to promote cognitive effort since cognitive processes greatly contribute to learning during the early stages of skill acquisition (Lee, Swinnen, & Serrien, 1994). Cognitive effort refers to the mental work involved in executive functions (Lee, Swinnen, & Serrien, 1994).

1.2 MOTOR LEARNING

Practice is generally considered to be one of the most important factors responsible for the relatively permanent change in one's ability to perform a motor skill. Motor learning theories attempt to describe the process of learning a motor skill, so that practice conditions can de designed for optimal skill acquisition. The motor learning theories discussed in this literature review will be; Adams (1971) closed-loop theory, Schmidt's (1975) schema theory, Guadagnoli & Lee's (2004) challenge point framework, and Fitts and Posner's (1967) stages of learning.

1.2.1 Closed Loop Theory and Schema Theory

Adams (1971) proposed that motor learning is the process of comparing the continual kinesthetic feedback to a reference of correctness, which is learned during practice, and is termed the perceptual trace. When an individual is performing a motor task, the position of that movement generates inherent feedback, which represents a particular location in space (Adams, 1971). The more that movement is practiced, the number of perceptual traces increases creating a collection, bringing the learner closer to their goal. Therefore, providing KR after every trial seemed vital to strengthening the perceptual trace, otherwise a resultant weak perceptual trace would elicit errors and hinder learning. Adams considered errors during practice to be harmful to learning, since the feedback from this error would increase the strength of an inaccurate perceptual trace.

In 1975, a new motor learning theory was proposed by Schmidt, termed the schema theory, to address some of the limitations of the closed-loop theory presented by Adams (1971), such as; the lack of emphasis on open-loop control processes. However, an appealing aspect to Adams' theory was the distinction between the memory state responsible for producing movements (ie. memory trace) and the memory state responsible for evaluating the movements (ie. perceptual trace). This aspect of Adams' closed-loop theory was allied in Schmidts' schema theory, such that the recall schema was equivalent to the memory trace and the recognition schema was equivalent to the perceptual trace. The schema theory states that relationships are formed based on experience. Similar to the perceptual trace from Adams' closed-loop theory, providing KR after every trial was vital to strengthening the recognition schema; however, errors were not considered to be detrimental to learning (Schmidt, 1975). Instead, errors were considered to improve the ability of the learner to accurately identify and correct errors (Schmidt, 1975).

The closed-loop theory (Adams, 1971) and schema theory (Schmidt, 1975) were challenged by studies that discovered practice conditions that consisted of a lower relative frequency of KR in comparison to a 100% KR condition may be more beneficial for learning and retention of various motor skills. For example, Oliveira, Correa, Gimenez, Basso, and Tani (2009) investigated the effects of a 100% KR schedule compared to a reduced relative frequency KR schedule of 25%, 50%, and 75%, during a bocce ball throwing task. Participants were required to throw a bocce ball as close to the target (bolim) as possible, which was placed at a distance of 12 meters. Participants in the 25% KR condition performed more accurately and consistently on the retention and transfer than the 50%, 75%, and 100% KR conditions. Based on the results, the authors agreed that since KR was not always available in the reduced KR condition, the learner was involved in an active process of retrieving information related to task-related intrinsic feedback, contributing to the enhancement of error detection and correction, compared to the 100% KR condition that is expected to become more reliant on KR. Providing 100% KR to the learner reduces the importance and meaning of the intrinsic feedback, while lessening the involvement of the participant during the skill acquisition process. Therefore, organizing practice conditions that lessen the cognitive effort involved to perform the motor skill hinders the learning process, adjusting for complexity of the motor task being learned.

1.2.2 Challenge Point Framework

Guadagnoli and Lee (2004) examined the concept of an optimal challenge point for learning based on skill the level of the learner and the difficulty of the task to be learned. This theory states that; 1. Learning cannot occur in the absence of information; 2. Learning will be hindered in the presence of too much or too little information; and 3. For learning to occur there is an optimal amount of information, which differs as a function of the skill level of the individual and the difficulty of the task to be learned (Guadagnoli & Lee, 2004). Motor tasks represent different challenges for performers of different abilities; therefore, the optimal challenge point differs for each learner. Ideally, the more simple a motor task is to a learner, the less information should be provided and vice versa; as the task becomes more complex, more information should be provided to the learner. With respect to the learning conditions of interest for this study, proactive and retroactive placement augmented information is a great example for describing the constructs of the challenge point framework. In the proactive condition, the task is simple in that, all the necessary information is provided to the learner prior to the learner attempting the motor response, then coupled with a 100% KR feedback schedule, the abundance of information temporarily improves the learners performance in acquisition, but hinders the learning process and overall acquisition of the motor skill. In contrast to proactive condition, the retroactive is optimally challenged. With the complexity of the task remaining the same, the placement of the information provides a level of added difficulty that engages the learner in a meaningful manner.

1.2.3 Stages of Learning

Fitts and Posner (1967) suggested that the learning process is sequential and that as we learn we move through specific stages. In 1967, Fitts and Posner developed a model to describe the process of learning, which consisted of three stages; the cognitive stage, the associative stage, and the autonomous stage.

1.2.3.1 Cognitive Stage

The first stage of learning a new motor task is cognitively demanding (Fitts & Posner, 1967). First, the novice must understand what the task is and the cognitive demands that are required to efficiently perform that task. Some exemplary questions by novices may be: What is my objective? How far should I move my left foot? What is the best position for my arm? Where should my left arm be when my right foot is here? Specific cues are significant during this stage since every detail is carefully analyzed because novice individuals are unable to decipher relevant information from irrelevant information (Fitts & Posner, 1967). Performances are generally inconsistent, slow, jerky, and uncoordinated. The cognitive stage is characterized by a large number of errors (Fitts & Posner, 1967). Tracing techniques such as; retrograde viral transport, have been used to map cortical networks during motor skill acquisition and error related processes

(Silkis, 2001). This method allows for the discovery of synaptic functional connections between various brain regions (Silkis, 2001). For this technique, a radio labeled virus is injected into a brain region attributed to a given function, the virus can then travel in a retrograde manor and highlight the networks associated with the efferent projections. It has been shown the basal ganglia and the cerebellum project into the ventral lateral nucleus of the thalamus that then projects to various cortical networks by using retrograde viral transport mechanisms (Silkis, 2001). The functional connections between these motor systems and higher cortical areas could allow the motor cortices to process error related movements in the cerebellum and motor cues within the basal ganglia (Schultz, 1998). If this is the case, then high number of errors generated by cognitively demanding and effortful motor tasks will be processed by higher cortical networks that will lead to increased synaptic alterations within the basal ganglia, limbic regions, and cerebellum. This cortically supports that errors are a required aspect of the successful progression through the stages of learning. In the study described above by Oliveira, Correa, Gimenez, Basso, and Tani (2009) it was concluded that the reduced KR group was more active in the process of interpreting intrinsic feedback, which enhanced their ability to detect and correct errors, resulting in higher retention scores. This is also seen in other practice conditions, such as proactive and retroactive placement of augmented information (Richardson & Lee, 1999). The participant in a proactive condition receives the augmented information prior to the response and replicates it, therefore, does not make many errors in acquisition (Richardson & Lee, 1999). However, when the augmented information is removed in retention a decrease in performance is observed (Richardson & Lee, 1999). Whereas, the retroactive participant receives the augmented information after their response allowing for comparisons to be made between their response and the correct response. Participants are then able to make any necessary adjustments (error correction) to ensure performance of the motor task is executed correctly in the future (Magill, 2001).

1.2.3.2 Associative Stage

The second stage of motor learning is characterized by the individuals' ability to associate environmental cues with the movements required to achieve the goal of the motor skill (Fitts & Posner, 1967). Environmental regularities allow the learner to anticipate required actions. Thus, the cognitive demand required to plan their movements for the task decreases (Fitts & Posner, 1967). The individual makes fewer errors since he or she has determined the most effective way to execute the task (Fitts & Posner, 1967). Although the fundamentals have been acquired, refinement of the skill is still necessary. The attention of the performer is focused on their own movements, and how these movements feel when performed accurately. Performance improvements are more gradual than in the cognitive stage and movements become more consistent (Fitts & Posner, 1967). Depending on the complexity of the skill to be learned individuals may stay in the associative stage of learning for varying amounts of time (Fitts & Posner, 1967).

1.2.3.3 Autonomous Stage

Automaticity is achieved during the final stage of learning. Automaticity is the ability to process information quickly while requiring little effort or attention to minor details, allowing the response to become automatic. Attention demands are decreased, thus, very little cognitive effort is required to plan the motor response (Fitts & Posner, 1967). Performances are very consistent during this stage. Functional independence of the motor skill is acquired through the ability of the individual to plan, execute, and evaluate the success of their response on their own (Lee, Swinnen, & Serrien, 1994). Once automaticity has been reached, individuals are able to detect their own errors and make the proper modifications to correct them (Fitts & Posner, 1967).

The theory presented by Fitts and Posner (1967) has been supported by cortical research. Functional magnetic resonance imaging (fMRI) can cortically capture neural network changes that are related to the stages of learning (Doyon, Song, Karni, Lalonde, Adams, & Ungerleider, 2001; Karni, Meyer, Jezzard, Adams, Turner, & Ungerleider, 1995; Muller, Kleinhans, Pierce, Kemmotsu, & Courchesne, 2002). Karni et al., (1995) examined the cortical changes within the motor cortex during a motor sequence task. Participants were instructed to complete the sequence as rapidly and accurately as possible. As practice continued, the speed and accuracy at which the sequence was performed increased until approximately three weeks when a plateau was reached. A decrease in activation was found in the cerebellum and prefrontal cortex as practice continued. An increase of activation also occurred within the motor cortex. These results suggest as a motor skill is learned there are distinct learning phases resulting in a new, more extensive cortical representation of the trained sequence within the primary motor cortex, possibly representing a site for long-term memory of the motor skill.

In summary, the stages of learning as proposed by Fitts and Posner are highly impacted by factors within the practice context. Motor skill acquisition may be accelerated or hindered based on these factors. An interesting aspect of the proactive and retroactive practice conditions is both of these conditions receive identical information; the only difference is when this information is provided. However, the advantages of practicing in a retroactive condition are significantly better for learning compared to the proactive condition (Patterson & Lee, 2005, 2008, 2010; Richardson & Lee, 1999). Thus, the condition in which a skill is practiced is critical.

1.2.4 Proactive and Retroactive Placement of Augmented Information

In a proactive condition, the augmented information to complete the motor action is presented before the participant completes his or her motor response, similar to observational learning (Richardson & Lee, 1999). Since all the necessary information to successfully complete the trial is provided before the motor response, participants do not need to invest a high level of cognitive effort to create a motor plan, for simple tasks in a closed environment. For example, in a study conducted by Patterson and Lee (2005), participants studied a series of English-personal data assistant (PDA) symbol pairing and then produced the PDA symbol on a digitizing tablet. In this type of practice condition, the information required to complete the motor response was readily available within the participants working memory. Working memory contains information that is retrievable for up to 30 seconds, after which it is lost if it is not repeated or rehearsed (Kalat, 2004). Since participants immediately reproduce the motor response and then move onto the next trial, the information to reproduce each motor response is always available in working memory. Thus, the structure of this practice condition decreases the difficulty of the task, initially resulting in high levels of success and less cognitive effort invested to complete the motor response during acquisition (Patterson & Lee, 2005, 2008, 2010; Richardson & Lee, 1999). However, the performance learning paradox states that changes during practice reflect temporary influences on performance and do not reflect learning of the motor skill (Schmidt & Lee, 2011). Thus, learning must be inferred through assessing one's performance on a retention test. Commonly two retention tests are performed; an immediate retention test, and a delayed retention test. The immediate retention test is preformed to detect initial learning differences between experimental groups during acquisition as a result of practice conditions. A delayed retention test is preformed to identify if any relatively permanent changes in the participants ability to perform the motor skill have occurred. Since sleep is a required to consolidate information in long-term memory, a delayed retention test is performed after a minimal 24 hour period (Siengsukon & Boyd, 2009; Walker, Brakefield, Morgan, Hobson & Stickgold, 2002). If a high level of performance is observed, it can then be inferred that learning has taken place. However, a decline in performance is demonstrated during retention when proactive participants are required to retrieve the motor response from working memory indicating that learning has not taken place, reflecting the performance learning paradox (Patterson & Lee, 2005, 2008; Richardson & Lee, 1999).

In a retroactive condition, participants receive augmented task information upon completion of their motor response (Richardson & Lee, 1999). Delivery of information in retroactive conditions include provision of augmented feedback, such as knowledge of results (KR) and knowledge of performance (KP) (Magill, 2001). Knowledge of results provides information regarding the accuracy of the response relative to the goal of the task while KP provides information regarding the quality of the movement that led to the performance outcome (Magill, 2001). Since augmented information is not provided until after the trial has been completed, the first time a motor response is attempted in a retroactive condition, the learner has no prior knowledge or reference of correctness for this initial motor response. During the early stages, the learner develops a reference of correctness used to retrieve the required motor response in later trials. The process of creating a reference of correctness and constantly retrieving the required information is considered cognitively demanding (Schmidt & Lee, 2011). The early trials have the greatest error, unless guessed correctly by chance (Fitts & Posner, 1967). In the context of proactive/retroactive studies this usually implies there is a high level of conceptual compatibility between the stimulus and the movement goal. As a function of practice, participants begin to learn the associated pairings and a decrease in errors is observed. During acquisition, participants tend to score poorly on recall success, with a gradual improvement as the practice continues (Patterson & Lee, 2005, 2008, 2010; Richardson & Lee, 1999). Performance enhancements over the course of the acquisition period result in decreased cognitive demands as a function of learning. During the retention test, high scores on recall success infer that learning has occurred.

Richardson and Lee (1999) suggested that a proactive practice schedule reduces the cognitively effortful processes required for learning a novel motor skill. The task for the study conducted by Richardson and Lee, required participants to learn 15 non-iconic letters of the American manual alphabet with augmented information provided by a model either prior to (proactive) or after (retroactive) attempted performances. Iconic letters are printed letters that visually correspond with the hand shapes of the manual alphabet (Richardson & Lee, 1999). Since iconic letters are quickly identified, easy to guess, and performance of them plateaus rapidly, these letters were removed as potential experimental stimuli. The model demonstrations were made via videotape, and participants' responses were recorded by videotape for later analysis. The participants' responses were rated on four parameters; formation (finger placement in the hand shape), hand orientation (wrist properly flexed or extended), plane (forearm properly pronated or supinated), and spatial location with respect to the torso. Performance of the proactive group during acquisition achieved near maximum levels, but dropped significantly during retention. The retroactive group displayed inferior levels of performance during acquisition, but superior performance during the retention tests, consistent with the performance-learning paradox. Retroactive participants were engaged in cognitively effortful practice and constantly retrieved information from long-term memory, this retrieval practice was attributed to the successful retention scores. These findings were supported by later research conducted by Patterson and Lee (2005, 2008, 2010).

Patterson and Lee (2005) conducted three experiments investigating the difficulty in learning various symbols representing the alphabet used to enter data into a personal digital assistant (PDA) and the interaction of item difficulty with practice conditions that promote varying levels of cognitive effort. The purpose of Experiment 1 was to categorize PDA characters as high, moderate, or low in conceptual compatibility based on the participant's results. Conceptual compatibility was operationally defined as the degree of spatial and motor relatedness between tracings of the English-script and the corresponding PDA typographic symbol (Patterson & Lee, 2005). An item similarity scale was used to assess 122 PDA symbols. On a sheet of paper participants were required to trace the English symbol in column one, then trace the corresponding PDA symbol in column two. Once finished tracing, participants reported the perceived similarity of the English symbol compared to the PDA symbol on a 7-point Likert scale in column three. Based on the participant's responses, the PDA symbols were respectively categorized by their conceptual compatibility.

In Experiment 2, it was found that as the compatibility of the English-PDA pairs decreased (high, moderate, low), participants displayed a systematic decrease in reaction time and increase in errors (Patterson & Lee, 2005). Finally in Experiment 3, the interaction of task complexity and practice condition (proactive/ retroactive) was examined by using the English-PDA pairs established from Experiments 1 and 2 (Patterson & Lee, 2005). Eighteen English-PDA symbols were used as experimental stimuli, therefore, there were 6 low compatibility, 6 moderate compatibility, and 6 high compatibility stimuli. Participants were required to produce PDA symbols of high, moderate, and low compatibility in response to English referents, using a PDA simulator. The practice conditions differed only in terms of when the complete English-PDA pair was presented, either prior to (proactive) or after (retroactive) an attempted recall. During acquisition, the retroactive practice schedule resulted in longer reaction times, longer study times, and decreased recall success scores for all PDA symbols, compared to the proactive practice group. However, during retention the retroactive group demonstrated superior learning of the PDA symbols, in comparison to the proactive practice group. Patterson and Lee's (2005) results were congruent with the results of Richardson and Lee (1999) concluding that for recall success, the high cognitive effort group (retroactive) retained the information better than the low cognitive effort group (proactive), regardless of the difficulty of the information to be learned, suggesting that the cognitively effortful processes required for the retroactive condition facilitated a more permanent memory for the PDA symbols. Patterson and Lee (2008) continued their work with proactive/

retroactive conditions by expanding and focusing on the spacing of repetitions during acquisition.

Patterson and Lee (2008) examined the relative contributions of the cognitive and motor components of learning under proactive or retroactive practice conditions by conducting two experiments. In the first experiment, participants were required to produce PDA symbols in response to English referents at different spacing intervals. Four groups were formed; the first division was into either proactive or retroactive conditions, then participants were subdivided into immediate succession (e.g. lag-0) or spaced practice order (e.g. lag-5). Participants in the lag-0 groups practiced the same PDA symbols on two consecutive trials compared to the lag-5 repetition schedule where participants experienced a delay of five intervening trials before completing a repetition of any given PDA symbol. Each trial consisted of three English-PDA pairs. Proactive participants demonstrated superior performance during acquisition, however, in retention retroactive participants demonstrated superior performance. These findings support the findings of Patterson and Lee (2005) and Richardson and Lee (1999). In the second experiment, a partial cued-recall paradigm was used to separate the effect of the number of times an item was studied from the number of times its retrieval was attempted. For each trial, 4 parings were studied, but only 1 was cued for recall. In concurrence with Patterson and Lee (2005) and Richardson and Lee (1999) it was found that during retention, retroactive participants successfully recalled PDA characters more often than their proactive counterparts.

Differential demands are placed on the memory system from practicing in a proactive or retroactive practice condition. Retrieval practice engages the cognitive process involved in facilitating learning (Bjork, 1988). The retrieval hypothesis presented by Bjork (1988) states that difficult successful retrievals are superior for memory formation than easier successful retrievals. As one retrieves memories, synaptic modification occurs altering its representation and increasing its sensitivity to facilitate the retrieval of that memory at a later point (Bjork, 1988). In the proactive condition, only working memory is engaged during acquisition since the necessary information required to complete the motor response is provided before their motor action. Thus, the proactive condition does not practice retrieval of information. However, the retroactive condition required participants to retrieve the information since augmented information was not provided until after the learner attempted the motor response. In accordance to this theory, Patterson and Lee (2005, 2008) and Richardson and Lee (1999) suggested that the retrieval hypothesis was the best explanation for the superior learning benefits observed from practicing novel motor skills in a retroactive condition.

It has been stated that the proactive and retroactive practice conditions differ in the cognitive demands placed on the learner (Patterson & Lee, 2005, 2008; Richardson & Lee, 1999). It has been inferred through behavioural measures and proposed as a theory to why the retroactive condition is superior for learning compared to the proactive condition. Although the synaptic transformation through the stages of learning has been captured cortically, to date, it is not known if one can track skill acquisition and learning through physiologic measures.

1.3 COGNITIVE EFFORT

Cognitive effort refers to the mental work involved in executive functions required for motor planning and error interpretation (Lee, Swinnen, & Serrien, 1994). Executive functioning that occurs during the learning of a motor skill can be promoted or hindered based on the conditions of practice. Different approaches have been used to measure cognitive effort during the acquisition of motor tasks. Objective measures used to infer cognitive effort within the motor learning literature include; recall success, study time, and reaction time. Based on previous literature by Patterson and Lee (2005), cognitively effortful practice results in an increase in study time, reaction time, and movement time, while displaying poorer recall success during acquisition. Through subjective measures researches are able to assess perceived cognitive effort of the participant and their interaction with the task by utilizing the NASA TLX. There is a strong connection between subjective and objective measures, a participant who perceives a task as being difficult typically displays behaviours that are paralleled in objective measures (ie. longer reaction time, study time, and movement time). However, subjective measures have many limitations including the participants' difficulty in distinguishing task demands from invested effort (Rivecourt, Kuperus, Post, & Mulder, 2008).

An alternative to objective and subjective measures are physiological indices, some of which include; pupillary response, cortisol, oxygen consumption, heart rate (HR), heart rate variability (HRV), and glucose metabolism. Most of these techniques rely on the measurement of metabolic correlates of cognitive activity that represent energy mobilization at a physiological level (Fairclough & Houston, 2004). However, while it is known that cognitive effort is required for leaning to take place, to date it has not been captured physiologically during motor skill acquisition. Potential physiological measures for this study included; glucose metabolism, pupillary responses, HR, and HRV. Each measure and their respective limitations are evaluated below, in support of the measure chosen, HRV. The current study utilizes a complimenting combination of subjective, objective, and physiological methods to gauge cognitive effort while learning a novel motor task.

1.3.1 Glucose Metabolism

While the brain is the most metabolically active organ, it does not possess a sufficient supply of glucose to execute all of its demands (Kennedy & Scholey, 2000). Thus, neural energy requirements must be met through a different mechanism, mainly oxidation of blood borne glucose (Kennedy & Scholey, 2000).

1.3.1.1 Process of Glucose Mobilization

When a task is cognitively demanding the limbic system is activated (Kalat, 2004). Specifically, the hippocampus is activated, which is responsible for the consolidation of new memories. The neural activation then continues to another part of the limbic system, the hypothalamus (Kalat, 2004). Once the hypothalamus is stimulated by the hippocampus it releases CRH (cortisol releasing hormone), which stimulates the anterior pituitary (Silverthorn, 2004). The anterior pituitary responds by the release of ACTH (adrenocorticotropic hormone) which travels via the bloodstream to its target organ, the adrenal gland. ACTH specifically stimulates the middle zone of the adrenal cortex, the Zona Fasciculata, which is responsible for the release of cortisol (a type of glucocorticoid) (Silverthorn, 2004). Once glucocorticoids are released they effectively increase plasma glucose (Silverthorn, 2004). The sympathetic nervous system is stimulated by this release of glucocorticoids thereby increasing HR and low frequency / high frequency (LF/HF) ratio (Saladin, 2004). The rate of transportation of blood borne glucose to the blood brain barrier is increased and once transferred across this barrier it is broken down and utilized (Saladin, 2004). Increases in local metabolism lead to an increase in transportation of glucose across the blood brain barrier (Kennedy & Scholey, 2000).

Physiological and psychological processes are strongly influenced and affected by blood glucose levels (Benton, Parker, & Donohue, 1997). Hypoglycemic levels of blood glucose (<2.2 mmol/l) for example, elicit trembling and confusion (Benton, Parker, & Donohue, 1997). However, fluctuations in blood glucose within a normative range may significantly influence cognitive performance. In recent studies, increasing the amount of glucose readily available to the body by glucose administration (25-50 g) significantly increased cognitive performance on demanding and effortful tasks, such as word recall (in which participants wrote as many words as they could remember from a list of 16 in 1 minute), word recognition (in which participants were presented with the original 16 words plus 16 distractors in a random order and instructed to identify the original words; Scholey, Laing, & Kennedy, 2006), computerized serial sevens (a task in which participants are presented with a starting number between 800- 999 from which they are instructed to serially subtract by sevens, as quickly and accurately as possible for 5 minutes), word retrieval (assessed long-term memory by having participants name as many words that started with the letter “A” or “S” within 2 minutes), word memory task (in which participants received 5 minutes to study a list of 15 words and then had to write down as many as they could remember within 1 minute; Scholey, Harper, & Kennedy, 2001), serial sevens (a task in which participants are presented with a starting number between 900- 1000 from which they are instructed to serially subtract by sevens out loud, as quickly and accurately as possible for 2 minutes), and word retrieval (assessed long-term memory by having participants name as many words that started with the letter "T" within 2 minutes; Kennedy & Scholey, 2000). The benefits of glucose administration on cognitive performance were particularly evident when tasks were demanding and effortful. For example, Kennedy and Scholey (2000) reported that elevated glucose improved performance on tasks requiring a high level of cognitive effort as seen in serial sevens, but had no effect on an easy version of the same task; serial threes (serial threes is identical to the serial sevens task, except it involves serial subtraction of threes).

Accelerated HR was found by Kennedy and Scholey (2000) to be associated with falling blood glucose concentration during the performance of a cognitively demanding arithmetic task leading to the hypothesis that an increased HR is a physiological mechanism serving to deliver glucose to active brain substrates (Fairclough & Houston, 2004; Scholey, Harper & Kennedy, 2001). This hypothesis is supported by research indicating cardiovascular responses were sensitive to the level of difficulty of different cognitive tasks, which included; serial sevens, word retrieval, and word memory tasks. Both HR and metabolic rate increased with greater cognitive load of a working memory task, allying the observation that supplemental glucose resulted in enhanced performance on tasks of higher cognitive effort. Scholey, Laing, and Kennedy (2006) concluded that during emotional processing glucose is liberated to optimize memory formation. Thus, increase in cognitive effort results in a higher demand for glucose (Scholey, Harper, and Kennedy, 2001). Subsequently, HR increases as a means of delivering the glucose to desired areas. Once HR is increased, a simultaneous increase in LF/HF ratio occurs.

1.3.1.2 Limitations of Glucose Measurements

A comparative study by Fairclough and Houston (2004) found both blood glucose and power spectral analysis (PSA) of heart rate variability (HRV) to be sensitive measurements for interpreting cognitive effort. Blood glucose and PSA of HRV measurements require control over similar parameters before an experiment can take place, such as; the time of day the experiment is conducted, exercise must be limited beforehand, and eating is limited, since metabolism, HR, and glucose levels are affected by these parameters. However, a limitation to glucose measurements is how invasive this technique is since many blood samples are required. Also, the measurements taken would be an indirect indication of the glucose utilized by specific brain structures.

1.3.2 Pupillary Response

Neurophysiologists have known for decades that pupils dilate in response to every cognitive process (Beatty, 1982; Granholm, Asarnow, Sarkin, & Dykes, 1996; Kahneman & Beatty, 1966; Karatekin, 2004; Piquado, Isaacowitz, & Wingfield, 2010). This is a very sensitive method that responds with an average latency of 100-200 ms after the onset of information processing and diminishes quickly once processing has finished. The dilator pupillae is controlled by the sympathetic nervous system and the sphincter pupillae is controlled by the parasympathetic nervous system, showing a major connection between the dilation of pupils and the stimulating system related to cognitive effort and memory formation (Van Gerven, Paas, Van Merriernboer, & Schmidt, 2004).

Hess and Polt (1964) were the first to notice this phenomenon during a study that consisted of solving multiplication questions that increased in difficulty. However, Kahneman and Beatty (1966) presented the first pupillometric analysis of pupillary responses during a short-term memory task. For their experiment, participants were required to repeat digit strings consisting of 3 to 7 digits (Beatty, 1982). The strings of digits were presented at a rate of 1 digit per second and after a 2 second delay, participants repeated the digits at the same rate. It was found that, pupil diameter increased with the presentation of each additional digit and pupil diameter decreased as each digit was spoken. If the participant were asked to repeat the digit string a second time, the pupil would re-dilate to the peak diameter for that string and then decrease with each digit spoken; reaching baseline measures after the last digit is spoken. The pupillary response created a steadily increasing slope that reached an asymptote; where no further dilation was recorded. This point occurred at approximately 7 digits, meaning that the pupillary response plateaued at the same point their working memory capacity was utilized (Miller, 1956). The pupil dilates proportionally as difficulty (quantity or complexity) increases in attention, memory, or interpretation of material; provided that some information processing capacity remains (Beatty, 1982). Pupil dilation will persist if demand is sustained. After learning has taken place, if the same material is requested the individual’s pupils will dilate while retrieving information and organizing a response, as each digit is spoken the pupil diameter decreases, reaching baseline after the last digit is spoken (Beatty, 1982).

1.3.2.1 Limitations of Pupillary Measurements

A major limitation for the use of pupillary responses for measuring cognitive effort, is that pupil diameter cannot be assessed during blinking (Siegle, Ichikawa, & Steinhauer, 2008). Blinks are recorded as missing data and estimates are filled in based on mathematical analyses. This was based on the assumption that blinking occurs randomly. However, it has been proposed that blinking may occur after a high cognitive load (Fukuda, 2001) or in preparation of information processing (Ohira, 1995). Research has found a relationship between short blink latencies and errors on cognitive tasks, possibly relating to an inadequate preparation. Pupil dilation often occurs just after blinking when performing a cognitive task (Sirevaag, Rohrbaugh, Stern, Vedeniapin, Packingham, & LaJonchere, 1999). A study conducted by Siegle, Ichikawa, and Steinhauer (2008) observed blinks to occur prior to a pupillary response, during periods of consistent cognitive effort and at the end of a cognitive load. Thus, pupil dilation may represent sustained information processing and blinking may represent the onset and offset of stimulus related information processing (Siegle, Ichikawa, & Steinhauer, 2008). Further investigation is required to determine the relationship between pupil dilation and blinking when analyzing the process of information processing.

A study conducted by Rivecourt, Kuperus, Post, and Mulder (2008) examined the effects of momentary changes in cognitive effort on cardiovascular and eye activity measures. Male pilots preformed an instrument flight task. The flight maneuvers to be performed varied in complexity. The flight profile lasted 28 minutes and consisted of flight maneuvers that had to be executed at specific times (e.g. Take-off to the north, a left horizontal turn, a right climbing turn, a left descending turn, etc). An increase in task load resulted in an increase in HR and LF/HF ratio. Although eye movements were sensitive to momentary changes in cognitive effort, this method could not distinguish between the rest period and task execution since baseline measurements cannot be established. Therefore it was concluded that, HR and PSA of HRV were the most sensitive measures for detecting changes in mental effort.

1.3.3 Heart Rate

An increase in HR may result from an increase in sympathetic activity, a decrease in parasympathetic activity, or from a combination of simultaneous changes within both systems (Borell, Langbein, Després, Hansen, Leterrier, Marchant-Forde, Minero, Mohr, Prunier, Valance, & Veissier, 2007). The dynamic relationship between these systems is complex. However, HR only provides information on the net effects of all components influencing cardiac activity. Therefore, it is difficult to assess the regulatory components of the autonomic nervous system with straightforward measurements of HR (Borell, et al., 2007). Thus, this is a major limitation to the use of HR in attempt to measure cognitive effort. Therefore, PSA of HRV is the optimal physiological measurement for the present study to capture cognitive effort during motor skill acquisition.

1.3.4 Heart Rate Variability

The autonomic nervous system (ANS) is composed of two delicately balanced systems working in opposition to maintain homeostasis; the sympathetic nervous system (SNS) responsible for the “flight or fight” response, and the parasympathetic nervous system (PNS) responsible for the “rest and digest” response (Luft, Takase, & Darby, 2009). The relative activity of these systems can be quantified through PSA of HRV, which is a non-invasive electrocardiographic measurement of ANS modulation (Sztajzel, 2004). HRV is a well-established technique that can be used to investigate the effect of cognitive effort on autonomic control of the heart (Blásquez, Font, & Ortís, 2009).

1.3.4.1 Measurement of Heart Rate Variability

The rhythm of the heart fluctuates from beat to beat, resulting in subtle variations in the time intervals between successive heart beats. This fluctuation is the result of changing ANS influences that affect cardiac activity, which functions to maintain homeostasis while adapting to environmental and intrinsic changes (Borell et al., 2007). These regulatory systems have the ability to act simultaneously or independently of one another, leading to the potential for multiple activation patterns that affect every heart beat (Borell et al., 2007). Each heartbeat consists of a QRS complex (see Figure 1) that defines the depolarization of the right and left ventricles of the heart, the time interval between the peaks of the R-spike from each QRS complex is compared (Blásquez, Font, & Ortís, 2009). The sinoatrial node “pacemaker” is located in the right atrium of the heart and generates the impulses that are conducted though the heart. The SA node consists of elongated and round cells (Borell et al., 2007). The round cells are capable of spontaneous depolarization that electrically stimulates the heart (Borell et al., 2007). In the absence of any influences, these cells fire at a rate of approximately 100 beats per minute, generating an intrinsic heart rate (Silverthorn, 2004). At rest, the sympathetic and parasympathetic systems are both tonically active, with a dominance of parasympathetic tone (Silverthorn, 2004).

When a stimulus is presented, the SA node responds to PNS innervation within one to two heartbeats, subsequently effecting HR within 5 seconds (Borell et al., 2007). SNS induced changes occur more slowly with initial response delays of up to 5 seconds, followed by a gradual increase and maximum response after 20-30 seconds (Borell et al., 2007). The anatomic structures of these two branches of the ANS are extremely different. Figure 2 displays the neurotransmitter mechanisms and synapse pathways for both the PNS and SNS. At the junction between the pre and post ganglion, both branches utilize acetylcholine as the neurotransmitter. However, at the terminal of the post ganglion the PNS utilizes acetylcholine, while the SNS utilizes norepinephrine, which is released at a slower rate (Borell et al., 2007).

Acetylcholine binds to muscarinic (M_2) receptors, a class of metabotropic G_i-proteins that are directly linked to potassium channels (Saladin, 2004; Silverthorn, 2004). When stimulated, the alpha subunit inhibits the cAMP dependent pathway by inhibiting adenylate cyclase activity, decreasing the production of cAMP and the beta gamma subunit of the G-protein activates potassium channels leading to a hyperpolarized internal state (Saladin, 2004; Silverthorn, 2004). This hyperpolarized state reduces the potential for the cell to reach threshold, resulting in a decreased HR and LF/HF ratio (Task Force of the European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996). Norepinephrine binds to alpha and beta adrenergic receptors, a class of G_q and G_s proteins respectively (Saladin, 2004; Silverthorn, 2004). The G_s alpha subunit stimulates the cAMP dependent pathway (Saladin, 2004; Silverthorn, 2004). Increased cAMP production results in an influx of sodium and activates protein kinase that phosphorylates calcium channels allowing for an influx of calcium as well (Saladin, 2004; Silverthorn, 2004). The increase of sodium and calcium entering the cell more quickly depolarizes the cell, thus action potentials are generated more frequently resulting in an increased HR and LF/HF ratio (Task Force of the European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996). In the synaptic cleft, these neurotransmitters are discarded in different manners; norepinephrine is cleared through reuptake and degradation whereas acetylcholine is converted into inactive metabolites (choline and acetate) by the enzyme acetylcholinesterase (Saladin, 2004; Silverthorn, 2004). This inactivation terminates signal transmission and metabolites are rapidly cleared from the synaptic cleft allowing for quicker signal conduction (Saladin, 2004; Silverthorn, 2004). Another major difference between the SNS and PNS is the type of conduction and where the preganglionic synapse ends. The PNS preganglionic synapses are myelinated and lie within the heart, in comparison to the SNS's unmyelinated preganglionic synapses that lie outside of the heart, accounting for the vast difference in response times (Borell et al., 2007).

Power spectral analysis (PSA) of HRV consists of analyzing the successive R-R intervals to determine the level of relative sympathetic and parasympathetic outflow to the heart over a given time period. The first step of PSA is to measure the time intervals between successive R spikes and plot this against beat number, creating a tachogram (see Figure 3). The tachogram consists of two defining characteristics; high frequency (HF) oscillations depicted by spikes and low frequency (LF) oscillations depicted by smooth waves. Mathematical analysis using a Fast Fourier Transformation separates the frequencies and graphically represents them in a power spectrum (see Figure 4). Fast Fourier transformation of the data indicates that oscillations are concentrated into three distinct frequency bands: very low frequency (VLF), low frequency (LF), and high frequency (HF) (Task Force of the European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996). The VLF band (≤0.04 Hz) contains data that is considered unresponsive to variations in cognitive effort since it is affected by thermoregulatory processes, peripheral vasomotor activity and the rennin-angio-tensin system (Cohen & Benjamin, 2006; Task Force of the European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996). The LF band (0.04-0.15 Hz) is related to fluctuations in the baroreceptor system and is mediated by sympathetic influences (Rivecourt, Kuperus, Post, & Mulder, 2008; Task Force of the European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996). The HF band (0.15-0.4 Hz) is primarily related to respiratory activity and is mediated by changing levels of parasympathetic influences (Rivecourt, Kuperus, Post, & Mulder, 2008; Task Force of the European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996).

1.3.4.2 Validation of Heart Rate Variability

In a study conducted by Pomeranz, Macaulay, Caudill, Kutz, Adams, Gordon, Kilbom, Barger, Shannon and Cohen (1985) spectral analysis of HRV was assessed by autonomic blocking agents. Atropine, a parasympathetic blocker, and Propranolol, a sympathetic blocker, were administered to study the effects on the HF and LF components of HRV. Administration of Atropine resulted in an almost complete loss of the HF component in the power spectrum. Since Atropine blocks acetylcholine, this indicated that the HF component corresponds to parasympathetic activity. Administration of Propranolol resulted in approximately 75% loss of the LF component in the power spectrum. However, when both Atropine and Propranolol was administered the remaining 25% of the LF power was diminished, indicating that the LF component corresponds to both sympathetic and parasympathetic activity. Since parasympathetic activity affects both the LF and HF, an increase in parasympathetic activity results in a lower LF/HF ratio, whereas an increase in sympathetic activity is indicated by a higher LF/HF ratio. Thus, Pomeranz and colleagues (1985) concluded that PSA of HRV may be used as an estimate of relative sympathetic and parasympathetic influence on autonomic cardiac control.

1.3.4.3 Neurovisceral Model of Heart Rate Variability

There has been an increase in psychophysiological research using HRV as an evaluation technique for identifying the interaction between the heart and the brain (Blásquez, Font & Ortís, 2009). Through various studies conducted by Hansen, Johnsen, and Thayer (2003, 2009), a link has been established between HRV and cognitive functions such as, attention and working-memory. Within working memory, information from the environment can be compared, manipulated and interpreted. Activity in the prefrontal cortex is increased during tasks that involve executive function and working memory (Hansen, Johnsen, & Thayer, 2003). A neurovisceral model created by Thayer, Hansen, Saus-Rose, and Johnsen (2009), explains the integration of specific neural structures that are involved in autonomic regulation and their relationship to HRV (Thayer, Hansen, Saus-Rose, & Johnsen 2009).

According to Thayer et al. (2009), there are direct and indirect pathways linking the frontal cortex to autonomic motor circuits that regulate cardiac function through sympathetic and parasympathetic pathways. The central autonomic network (CAN) controls visceromotor, neuroendocrine, and behavioural responses that are critical for goal directed behaviour. The CAN consists of prefrontal and limbic structures: anterior cingulate, insular, orbitofrontal, and ventromedial prefrontal cortices; central nucleus of the amygdala; paraventricular and related nuclei of the hypothalamus; periaquaductal gray matter; parabrachial nucleus; nucleus of the solitary tract (NTS); nucleus ambiguous; ventrolateral and ventromedial medulla; and the medullary tegmental field (Thayer & Brosschot, 2005). All of these structures are reciprocally interconnected with the primary output of the CAN being mediated through the stellate ganglia for the sympathetic system and the vagus nerve for the parasympathetic system. Preganglionic neurons from these systems originate from the CAN and project to the heart, while projections from the heart and other organs transmit sensory information back to the CAN (Thayer & Brosschot, 2005). Thus, the CAN is directly linked to HRV and HRV is an indicator of CNS-ANS activity (Thayer & Brosschot, 2005; Thayer, Hansen, Saus-Rose, & Johnsen 2009).

A study conducted by Tattersall and Hockey (1995) examined flight engineers during training. They concluded that cognitively effortful knowledge-based problem solving periods was associated with an increased LF/HF ratio compared to routine well-learned procedures. A study conducted by Wilson, Smith, and Holmes (2007) examined a golf-putting task to test the role of effort in influencing the effects of anxiety. The high anxiety and low anxiety groups were assessed through self-report, HRV, putt time, and the number of glances at the target. Throughout the study, conditions that required increased cognitive effort or conscious processing resulted in increases in LF/HF ratio and self-reported significantly higher effort invested in the competitive condition on the Rating Scale for Mental Effort (RSME). A study conducted by Hansen, Johnsen, and Thayer (2003) studied Royal Norwegian sailors on various working memory and continuous performance tests to investigate the effects of vagal tone on executive and non-executive tasks. The high HRV group demonstrated faster reaction times, performed better on the working memory test and continuous performance test, provided more true positive responses, and less false positive responses, compared to the low HRV group. Importantly, there were no differences between groups on the non-executive simple reaction time and choice reaction time tasks, substantiating the effects to those involving executive function. Finally, Luft, Takase, and Darby (2009) investigated HRV and cognitive performance before and after physical effort. Their results were consistent with past research, supporting that HRV is related to cognitive demand and discovered that the correlation between HRV and cognitive performance is stronger after exercise. Many studies offer considerable support for the use of frequency based measures of HRV as an indicator of cognitive effort; however, to the best of our knowledge, no study has examined the acquisition of a motor task in practice conditions manipulating the investment of cognitive effort of the learner.

1.3.4.4 Limitations of Heart Rate Variability

HRV is a sensitive measurement that can be effected by many variables (Sztajzel, 2004). Age, gender, exercise, body position, breathing rate and diseases are some examples of parameters that need to be controlled for when using this measurement tool. Also, since HRV analyzes variations between consecutive RR intervals, the measurement is limited to individuals that have a normal sinus rhythm and a low number of ectopic beats.

Most studies up to this point have focused on the use of HRV to predict pathological conditions, and defining differences between populations. Within the motor learning field, to date, no known studies have used HRV measures as an estimate of cognitive effort during motor skill acquisition. A limitation to past studies is the method that HRV data was collected. Specifically, measurements were based on performance, not learning. The present study was unique in that HRV data was collected during both acquisition and retention, allowing for cognitive effort to be assessed through the stages of learning.

CHAPTER 2: INTRODUCTION

2.1 STATEMENT OF THE PROBLEM & PURPOSE

To date, no known research has investigated the physiological responses of cognitive effort during motor skill acquisition. Currently, there are no known articles in the motor learning area of research to use HRV as a method of capturing cognitive effort despite the ability of HRV to assess fluctuating sympathetic and parasympathetic influence on cardiac activity. Traditionally, cognitive effort has been inferred through behavioural measures, such as reaction time or movement error. The proactive and retroactive practice conditions were chosen for this study since previous work conducted by Patterson and Lee (2005, 2008) and Richardson and Lee (1999) established that the proactive condition requires a low investment of cognitive effort, whereas the retroactive condition requires a high level of cognitive effort to plan a motor response. Thus, the purpose of the present thesis was to extend existing research by examining the differential impact of the proactive and retroactive practice conditions on the physiological responses of the learner. A preliminary experiment was designed to aid in the decision process of experimental stimuli for Experiment 2. The experimental predictions for Experiment 2 are outlined below.

2.2 HYPOTHESES

Based on the literature, it is hypothesized that:

1. Participants placed into the retroactive condition would display inferior recall success compared to the proactive condition in the acquisition period (Patterson & Lee, 2005, 2008, 2010; Richardson & Lee, 1999).

2. Participants placed into the retroactive condition would display superior recall success compared to the proactive condition in the retention period (Patterson & Lee, 2005, 2008, 2010; Richardson & Lee, 1999).

3. During acquisition, it is expected that the LF/HF ratio would be directly proportional to the cognitive effort utilized for a specific cognitive task. Specifically, participants in the retroactive condition are expected to invest higher cognitive effort during acquisition, resulting in a larger increase in the participants' LF/HF ratio compared to the proactive condition (Pomeranz, et al., 1985; Rivecourt, Kuperus, Post, & Mulder, 2008, Wilson, Smith, & Holmes, 2007).

4. During the retention portion of the experiment, it is expected that the LF/HF ratio would be directly proportional to the cognitive effort utilized for a specific cognitive task. As a function of learning, the retroactive condition was expected to invest lower cognitive effort during retention, resulting in a lower increase in the participants' LF/HF ratio compared to the proactive condition (Pomeranz, et al., 1985; Rivecourt, Kuperus, Post, & Mulder, 2008, Wilson, Smith, & Holmes, 2007).

CHAPTER 3: EXPERIMENT 1

Experiment 1 was designed to determine the level of conceptual compatibility between Braille-sequences and their associated English-script pairs. This is similar to the first steps taken by Patterson and Lee and Richardson and Lee for their work with secondary languages to determine the level of conceptual compatibility between the secondary language and the English translation. For this study, conceptual compatibility was operationally defined as the degree of spatial and motor relatedness between an English-script and the corresponding Braille-sequence (Patterson & Lee, 2005). English-script Braille-sequence pairs with a low level of conceptual compatibility was defined as pairs with a low degree of spatial and motor relatedness. English-script Braille-sequence pairs with a high level of conceptual compatibility was defined as pairs with a high degree of spatial and motor relatedness. The level of conceptual compatibility was assessed by participants' responses. When an English-script Braille-sequence pair was guessed correctly, it suggested a high level of conceptual compatibility. When the English-script Braille-sequence pair was enigmatic, it indicated a low level of conceptual compatibility. A secondary purpose of this experiment was to determine if a tactile stimulus could be transferred into a serial motor response.

Braille consists of six dots within a cell, encoded by raising different combinations of dots. Braille was chosen as the template for the novel sequence since most individuals have very little experience with Braille, providing a level of novelty that was a required asset to this experiment. Similar to previous proactive/ retroactive studies (Patterson & Lee, 2005, 2008, 2010; Richardson & Lee, 1999) participants were required to learn a novel language. For example, Patterson and Lee, (2005, 2008, 2010) used PDA characters and Richardson and Lee (1999) used manual gestures of the American Sign Language as their novel motor skill. PDA characters, sign language, and Braille all possess varying levels of conceptual compatibility across the different English-script translations.

3.1 METHOD

3.1.1. Participants

Six (3 male and 3 female, *M* age= 24.0 years, *SD*= 1.1) volunteers from Brock University participated in an English-script Braille-sequence pairing task. The English-script was a letter, number, or symbol associated with a Braille motor sequence, requiring the participant to press between 1 to 5 keys. All participants were self-declared right handed and reported no experience or knowledge of secondary languages, including Braille. Participants provided informed consent prior to their participation.

3.1.2. Experimental Task

The task required participants to enter a series of motor sequences in response to English-script primes without the associated Braille motor sequence. Six keys were coded with the colour pink representing each of the six dots in the Braille cell. The "Home" key that initiated and completed each sequence was coloured green (see Figure 5). Each of the 43 Braille-sequences consisted of 1 to 5 keystrokes performed in a specific order (see Figure 6). Participants were presented with one of the English-script primes and then they were instructed to motorically depress between 1 and 5 keys they perceived would best represent the English-script prime.

3.1.3. Apparatus

For the duration of the experiment, participants were seated in a chair 45 cm high from the ground. They were placed in front of a standard desk, 71 cm high which supported a 19 inch Dell monitor at a distance of 48.5 cm from the participant, a 42 cm x14 cm Dell keyboard at a distance of 22 cm from the participant and a 13 cm x 6.5 cm Dell mouse at a distance of 22 cm from the participant. The images on the screen were 20.5 cm x 14 cm. Only the mouse and seven number keys on the keyboard were used for this experiment. The seven keys utilized were colour coded and visually represented the Braille cell. The keys were 1.2 cm x 1.2 cm with 0.5 cm between each key (see Figure 5). On the number pad, the number keys (1, 2, 4, 5, 7, and 8) were used as the 6 pink keys and the number 0 was used as the green “Home” key.

The experimental stimuli consisted of 43 English-script Braille-sequence pairs. The corresponding sequences were between 1 and 5 keystrokes in length, which consisted of: two 1-keystroke sequences, ten 2-keystroke sequences, fifteen 3-keystroke sequences, fourteen 4-keystroke sequences, and two 5-keystroke sequences. All participants completed one repetition of these pairs. Participant’s key pressing entries were automatically recorded by E-prime version 1.1.

For this experiment, Braille was transferred from a tactile stimulus into a motor stimulus presented by E-prime. E-prime allowed for an easy transfer medium because the Braille cell could be visually recreated within the program. The responses were accurately recorded from a number pad designed to be visually compatible with the images in E-prime (see Figure 5). E-prime collected the dependent variable of interest, success rate. Success rate was recorded on every trial. A successful trial consisted of the correct key pressing sequence being entered in response to the English-script stimulus.

3.1.4 Experimental Procedure

Before testing, participants read through a series of instruction screens presented in E-prime explaining the experimental procedure. Participants self-determined the length of time they viewed each instruction screen. Figure 7 is an instruction screen designed to explain to participants how to properly enter sequences. This figure shows the English-script letter "L" and its Braille-sequence. The Braille-sequence is depicted by black dots. The numbers illustrate the order in which they must be pressed to be correct. Braille-sequences must be entered from top to bottom in the left column and then from top to bottom in the right column. Following this screen, there was an example and explanation of the procedure. Once the participant had been informed of the process, he or she completed two practice trials. The English-script Braille-sequences used during the practice trials were not used during the experimental procedure. Questions were encouraged at any time during the practice trials.

At the beginning of each trial, the participant would view a "Ready?" screen for 1000 ms just prior to viewing an English-script prime. Each English-script prime would appear with a blank Braille cell to the right of that script (see Figure 8). The duration the English-script prime appeared on the screen was self-determined by the participant. When ready, the participant would press the "Home" key (coloured green) to begin their response. Once the "Home" key was depressed, the image would disappear and a blank navy blue screen would be displayed on the monitor for the duration of their response.

Participants would then depress 1 to 5 response keys (coloured pink) based on their perception of what the complete pairing would look like. Upon completion of the key presses, participants would depress the “Home” button to complete the trial. A “Trial Complete” screen would then appear for 2000 ms before proceeding to the next trial. The experimental session consisted of 43 trials. Upon completion of each trial the responses were recorded by E-prime as correct or incorrect. The duration of the testing period was approximately 30 minutes. No feedback was provided during these trials. Feedback was unnecessary because participants were not required to learn any of the English-script Braille-sequence parings since the purpose of Experiment 1 was simply to determine the level of conceptual compatibility for each stimuli.

3.1.5. Statistical Analyses

Descriptive statistics were conducted for all 43 English-script Braille-sequence pairings. Correct answers were recorded as 1 while incorrect answers were recorded as 0 by E-prime. The frequency of success rate was determined for each English-script Braille-sequence pair by averaging the number of correct responses provided by the participants. A predetermined elimination criterion of correct responses equal-to or above one correct response was created prior to the analyses. Only enigmatic English-script Braille-sequence pairs could provide the level of novelty necessary for Experiment 2.

3.2. RESULTS

Forty-three English-script Braille-sequence pairs were analyzed; the descriptive statistics are displayed in Table 1. The first column of the table lists the correct response sequences; the second column lists the corresponding English-scripts; the third column lists the means of how many times a Braille-sequence was entered correctly and the fourth column lists the number of times each Braille-sequence was entered correctly. Each English-script Braille-sequence paring was seen only once by each participant. Thus, there was a possibility of six correct answers per English-script. The English-scripts “1”, “single quote”, “dash”, “Q” and “8” were each entered correctly once. The English-scripts “H” and “X” were entered correctly twice. All participants entered all other sequences incorrectly.

3.3. DISCUSSION

The purpose of Experiment 1 was to determine the conceptual compatibility of 43 English-script Braille-sequence pairs. The results of Experiment 1 suggest the majority of the English-script Braille-sequence pairings were enigmatic, thus suggesting a low level of conceptual compatibility between these English-scripts and their corresponding Braille-sequence. The purpose of determining if English-script Braille-sequence pairs were conceptually compatible was to aid in the decision process of selecting stimuli for Experiment 2. English-script Braille-sequence pairs with a high level of conceptual compatibility were rejected as experimental stimuli to ensure the task was novel to all participants and the level of compatibility was equated.

There were few instances where the sequence that represented the English-script Braille-sequence pair was conceptually compatible and answered correctly (“1”, “single quote”, “dash”, “Q”, “8”, “H”, and “X”). These English-scripts were removed from the list of potential experimental stimuli. However, the only exception was the number “1” English-script, since it was needed to maintain an equal balance of six experimental stimuli in each of the different 2-keystroke, 3-keystroke, and 4-keystroke groups. The number “0” and the “single quote” were removed since they were difficult to visually distinguish from the letter “O” and the “comma” respectively during the beginning of each trial when the English-script is paired with a blank Braille cell (see Figure 9). Thus, one may view the letter “O” appear as a prime and respond as if they had viewed the number “0” and enter the incorrect sequence even though it should have been a correct trial. All English-scripts that were 1 or 5 key presses in length were also removed since there were not enough of them to make a complete group of six experimental stimuli.

CHAPTER 4: EXPERIMENT 2

4.1 PARTICIPANTS

This experiment included twenty-four participants from the Brock community aged 18-35 (M= 23.9, SD= 2.8). Exclusion criteria included the following; left handed individuals, individuals with prior experience or knowledge of Braille, high level athletes, and individuals with heart or anxiety disorders. Individuals with heart disorders were excluded since they have a lower resting LF/HF ratio (Cohen & Benjamin, 2006; Sztajzel, 2004; Thayer, Hansen, Saus-Rose, & Johnsen 2009). Participants self-reported to have no known history of heart conditions or anxiety disorders that would impact their participation in the study. High-level athletes were excluded from this experiment since they have a higher resting LF/HF ratio (Achten & Jeukendrup, 2003; Hansen, Johnsen, Sollers, Stenvik, & Thayer, 2004; Thayer, Hansen, Saus-Rose, & Johnsen 2009). For this study, varsity or high-level athletes were defined as those who exercise 15 hours or more per week. All participants were self-declared to be right handed and have no prior experience or knowledge of secondary languages, including Braille. The participants were equally distributed and randomly separated into either the proactive or retroactive condition. Gender and time of day tested was counterbalanced across experimental groups. Gender was counterbalanced since females have a lower resting LF/HF ratio (Bonnemeier, Wiegand, Brandes, Kluge, Katus, Richardt, & Potratz, 2003). Time of day tested was counterbalanced to compensate for varying circadian rhythms (Bonnemeier, et al., 2003; see Table 2).

4.2 EXPERIMENTAL TASK

Participants were required to enter a series of motor sequences in response to English-script primes. All motor sequences consisted of 2 to 4 keystrokes in length, entered in a pre-defined order (see Figure 6). Braille-sequences had to be entered from top to bottom in the left column and then from top to bottom in the right column. Experiment 2 consisted of 18 sequences subdivided into three categories; 2-keystroke sequences, 3-keystroke sequences, and 4-keystroke sequences (see Appendix A). Each category consisted of six sequences. The English-script Braille-sequence pairings used as the experimental stimuli were selected based on participant responses from Experiment 1 and an even distribution across all levels (horizontal and vertical) of the Braille cell. Thus, each Braille dot is utilized and pressed within each 2-keystroke, 3-keystroke, and 4-keystroke sequence group. Also, within each keystroke group, there is a letter English-script (see Figure 10), number English-script (see Figure 8) and a symbol English-script (see Figure 11).

There were six potential response keys coded with the colour pink that represented the six dots in the Braille cell. The only other key used by participants was the “Home” key that initiated and terminated the motor responses, this key was coloured green (see Figure 5). Participants were instructed to motorically depress between 2 and 4 keys in response to English-script primes.

Based on the pre-test, the tactile stimulus was successfully transferred into an overt motor response to be utilized for the present experiment. This task was chosen based on its novelty and its ability to place differential demands on the cognitive processes of the learner. Images of the English-script Braille-sequence pairings were created and uploaded into E-prime. E-prime collected the dependent variables; recall success (RS), study time (ST), and reaction time (RT). Recall success was the number of pairings the participant entered correctly. Study time was the length of time the participant studied the English-script Braille-sequence pairings. Reaction time was measured from the presentation of the English-script prime without the Braille-sequence to movement initiation. See Figure 12 for a visual representation of the dependent variables collected in the experimental procedure.

4.3 PRE-EXPERIMENTAL PROTOCOL

The study protocol and any associated risks involved with participation were explained to each participant before written consent was obtained. Participants were naive to the purposes of the experiment and none had participated in Experiment 1. This study was approved by the research ethics board of Brock University (File # 09-272; see Appendix F). Prior to participation, participants were requested to refrain from vigorous exercise, smoking, alcohol, and caffeine for 24 hours before the study and eating for 2 hours before the study (Fairclough & Houston, 2004; Luft, Takase, & Darby, 2009). Once ready, the ECG electrodes were attached to the participant. The ground lead was placed on the left side of the participant’s chest, superior to the heart; the positive lead was placed on the left side of the participant’s chest inferior to the heart; and the negative lead was placed on the right side of the participant’s chest directly across from the positive lead (Hansen, Johnsen, & Thayer, 2003). If the participant had anything obstructing or interfering with the signal produced by the monitor then it was removed (e.g. hair), this was accomplished by shaving the required area (Millar, Sampson, &

Soukup, 1985). Alcohol swabs were used to sterilize and abrade the area where the electrodes would be applied (Millar, Sampson, & Soukup, 1985). Gentle skin abrasion reduces skin impedance by removing dead skin cells and oily residues (Millar, Sampson, & Soukup, 1985). By exposing the inner conductive layer of the epidermis it improves trace quality and reduces artifact (Millar, Sampson, & Soukup, 1985). An artifact is defined as any recorded activity that is not of cardiac origin and may arise from physiologic (ie. generated from the participant) or extraphysiologic sources (ie. generated from external sources; equipment, environmental; Millar, Sampson, & Soukup, 1985). Adhesive gel was applied to secure the electrodes in place. Each participant was informed of the highly sensitive nature of the ECG equipment; thus, participants were instructed to limit talking, coughing, sighing, and unnecessary movement (Fairclough & Houston, 2004). Prior to the beginning of the experiment, the participants were asked to sit in an office chair in a dark quiet room with their eyes closed and wearing acoustic impeding devices for 10 minutes (Fairclough & Houston, 2004). This was to ensure that the participant was in a resting state for the baseline measurements. Then a baseline reading of the individuals ECG was obtained for a duration of 5 minutes (Hansen, Johnsen, & Thayer, 2003; Sztajzel, 2004). A baseline reading was obtained at the beginning of each experimental session and ECG data was collected for the duration of the session. Sampling was recorded at 1000Hz to ensure an accurate R spike was recorded (Fairclough & Houston, 2004).

Ectopic heartbeats were excluded from analysis, with an allowance of less than 1% to ensure data integrity (Task Force of the European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996). Ectopic beats are defined as any heartbeat that originates from somewhere other than the SA node, characterized on an ECG recording by a quick beat succeeding a regular SA node induced heartbeat, followed by a long pause before the next SA node stimulated heartbeat (Saladin, 2004). Identification and removal of artifacts occurred by automated omission prior to analysis.

4.4 EXPERIMENTAL PROCEDURE

4.4.1 Acquisition Phase

The participants remained in a seated position for the acquisition period once a baseline measurement of each participant's ECG was established. The equipment set up for Experiment 2 was identical to that of Experiment 1. The acquisition phase began with participants viewing a series of instruction screens presented by E-prime. Participants self-determined the length of time each screen was presented to ensure comprehension.

Following the instructions, participants performed two practice trials of their respective experimental procedure. The English-script Braille-sequences used during the practice trials were not used during the experimental procedure. Questions were encouraged at any time during the practice trials.

The acquisition period consisted of 18 English-script Braille-sequence pairs repeated eight times each for a total of 144 acquisition trials. Every participant completed the same experimental stimuli in the same order, with no two consecutive sequences requiring the same number of keystrokes (see Table 3 for sequence orders). The duration of the testing period was approximately 1 hour.

4.4.1.1 Proactive Procedure

At the beginning of each trial, participants view a “Ready?” screen for 2000 ms (see Figure 12 for a typical trial procedure for the proactive condition). Next, participants were presented the English-script prime with its associate Braille-sequence to the right (see Figure 13). Participants self-determined the amount of time they studied the English-script Braille-sequence pair on the computer screen. Once finished they depressed and held the “Home” key to terminate the screen. An image of the English-script prime replaced it, when ready participants released the “Home” key to begin their motor response. Upon the release of the “Home” key, the image disappeared and was replaced with a blank navy blue screen for the duration of their response. Participants were required to depress between 2 and 4 response keys to reproduce the Braille-sequence based on the English-script pair previously viewed. Once participants completed their response, they depressed the “Home” key to end the trial. Participants immediately received qualitative feedback on the monitor in the form of a statement; “Your response was correct” or “Your response was incorrect.” This feedback was displayed for 3000 ms. After this blank screen, a “Trial Complete” screen was displayed for 2000 ms. E-prime determined the success of the participants’ motor responses by coding a correct response as 1 and an incorrect response as 0. The duration of all acquisition trials were equated for the proactive and retroactive conditions. At the beginning of each trial, E-prime sent a 3 V electrical signal to the ECG monitor through a separate input to ensure that all dependent variables were accurately analyzed together. This trigger lasted for the duration of one trial and terminated after the trial complete screen.

4.4.1.2 Retroactive Procedure

Figure 12 is a visual depiction of the retroactive procedure during a trial. At the beginning of each trial, participants viewed a “Ready?” screen for 2000 ms. Participants then viewed the English-script prime without its associated Braille-sequence (see Figure 8). Participants self-determined the amount of time the English-script prime was presented. When ready, participants depressed the “Home” key to begin their response. Upon release of the “Home” key, the prime disappeared and a blank navy blue screen was displayed for the duration of the participants’ response. Participants were required to depress between 2 and 4 keys based on the English-script prime. Once participants completed their response, they depressed the “Home” key to end the trial. Participants immediately received qualitative feedback on the monitor as either; “Your response was correct” or “Your response was incorrect” based on their just completed response. Feedback was displayed for 3000 ms. Following this screen, participants then viewed the complete English-script Braille-sequence (see Figure 13). Similar to the proactive condition, the length of time participants studied the pairing was self-determined. Upon completion of viewing the pairing participants depressed the “Home” key, a “Trial Complete” screen was then displayed for 2000 ms. E-prime determined the success of the participants’ motor responses by coding a correct response as 1 and an incorrect response as 0. At the beginning of each trial a trigger in E-prime sent a 3 V electrical signal to the ECG monitor through a separate input to ensure that all dependent variables were accurately analyzed together. This trigger lasted for the duration of one trial and terminated after the trial complete screen.

After the acquisition period, participants were instructed to fill out the modified NASA task load index questionnaire (Hart & Staveland, 1988) to assess perceived cognitive load required to learn the English-script Braille-sequence pairs (see Appendix B). This multi-dimensional rating-scale provided an overall workload score based on weighted averages from six subscales: mental demands, physical demands, temporal demands, own performance, effort, and frustration. All questions were answered based on a modified 20 point scale, adjusting for how the participants completed the questionnaire. Only the latter portion (last three subscales) of the test was utilized for statistical analysis, since these questions are designed to interpret the participants' interaction with the task and their perceived level of difficulty. All participants were then given a 15 minute break before performing an immediate retention test. During the 15 minute break, participants continued to sit in the office chair with the room remaining dark and quiet. Participants' eyes were closed and acoustic impeding devices were worn for the 10 minute rest period and a second baseline measurement of the participants ECG. ECG baseline data was collected for 5 minutes.

4.4.2 Retention Phase

The immediate and 24-hr post retention tests consisted of all 18 English-script Braille-sequences used during the acquisition period to ensure the duration of the retention tests were long enough to record accurate ECG data for PSA of HRV (Hansen, Johnsen, & Thayer, 2003; Sztajzel, 2004). The English-script Braille-sequences were placed in a different order then the acquisition period to eliminate the potential for an order effect. An English prime and Braille prime retention test was designed to eliminate the potential for a specificity of practice effect. Altogether, there were 4 retention tests designed; English prime retention test order A, English prime retention test order B, Braille prime retention test order A, and Braille prime retention test order B (see Table 3). Each participant completed all 4 of these tests counterbalanced by receiving version A or B as their immediate or delayed retention test.

4.4.2.1 English Prime Retention Procedure

Both prime retention test trial procedures were conducted in the same manner. Calculations of HRV data followed the same procedures as in the acquisition phase. First, the participants read a series of instruction screens. Figure 12 is a depiction of the trial procedure during the retention period. At the beginning of each trial a “Ready?” screen was displayed for 2000 ms. Following this screen, an English-script prime appeared without the associated Braille-sequence. Participants self-determined the amount of time they viewed the English-script prime. Once ready, the participants released the green “Home” key to begin their response and depressed the “Home” key upon completion of their response. During their response the screen was blank and navy blue, similar to the response screen during the acquisition period. Participants were required to recall from memory the key pressing sequence with the associated English-script prime. Upon completion of their response and depression of the “Home” key, participants viewed a “Trial Complete” screen for 2000 ms. E-prime determined the success of the participants’ motor responses by coding a correct response as 1 and an incorrect response as 0. Importantly, no feedback was presented during the immediate or delayed retention test. At the beginning of each trial a trigger in E-prime sent a 3 V surge of electricity to the ECG monitor through a separate input to ensure that all dependent variables were accurately analyzed together. This trigger lasted for the duration of one trial and terminated after the trial complete screen. Upon completion of the English prime retention test, participants completed the modified NASA TLX questionnaire (Hart & Staveland, 1988).

4.4.2.2 Braille Prime Retention Procedure

The final portion of the experiment, required participants to identify the Braille-sequences presented in E-prime and write on a cue card what the corresponding English-script was. All 18 of the experimental stimuli were included for the Braille prime retention test. First, the participants read a series of instruction screens. At the beginning of each trial a "Ready?" screen was displayed for 2000 ms. Following this screen, a Braille-sequence appeared without the associated English-script. Participants self-determined the amount of time they viewed the Braille-sequence. Once ready, the participants wrote their response on a cue card presented by the researcher. Upon completion of their response and depression of the "Home" key, participants viewed a "Trial Complete" screen for 2000 ms. The cue card was then taken away; a new cue card was presented for each trial. Importantly, no feedback was presented during the immediate or delayed Braille prime retention test. The researcher manually recorded all answers in an excel file as 1 for correct and 0 for incorrect. Upon completion of the Braille prime retention test, participants completed the modified NASA TLX questionnaire (Hart & Staveland, 1988).

Summary of experimental procedure:

Day 1

- Consent form and inclusion criteria (2-3 minutes)
- Rest period (10 minutes)
- Baseline ECG measurement for PSA of HRV (5 minutes)
- Experimental instructions (5 minutes)
- Practice trials (2-3 minutes)
- Acquisition Phase (45 minutes)
- NASA questionnaire (2-3 minutes)
- Rest period (10 minutes)
- Baseline ECG measurement for PSA of HRV (5 minutes)
- English prime retention test- Immediate (5 minutes)
- NASA questionnaire (2-3 minutes)
- Braille prime retention test- Immediate (5 minutes)
- NASA questionnaire (2-3 minutes)

Day 2

- Rest period (10 minutes)
- Baseline ECG measurement for PSA of HRV (5 minutes)
- English prime retention test- Delayed (5 minutes)
- NASA questionnaire (2-3 minutes)
- Braille prime retention test- Delayed (5 minutes)
- NASA questionnaire (2-3 minutes)

4.5 STATISTICAL ANALYSIS

For each trial, recall success (RS), reaction time (RT), and study time (ST) were recorded by E-prime. A three lead ECG was used for all ECG data collection and recorded using Powerlab. The acquisition phase consisted of 144 trials equally divided into 8 blocks (consisting of 18 trials each; see Table 2). All measures were analyzed separately in a 2-Practice Condition: (proactive, retroactive) by 8-Block ANOVA for RS, RT, ST, and PSA of HRV. For each of the 8 blocks of ECG data, the time intervals between successive R waves were plotted against beat number, creating a tachogram. Through a fast Fourier Transformation analysis the frequencies were then separated into LF (0.04 Hz- 0.15 Hz) and HF (0.15 Hz- 0.4 Hz) oscillations and graphically represented in a power spectrum. A LF to HF ratio was determined by the power of each frequency; the ratio alters accordingly giving insight to which system is influencing cardiac modulation. Baseline measurements of ECG were obtained, and then all subsequent block values were divided to determine the relative change in LF/HF ratio. LF/HF ratios were averaged and analyzed by a 2-Practice Condition: (proactive, retroactive) by 8-Block ANOVA. All effects sizes were calculated using partial eta squared.

For the English Prime retention phase, RS, RT, and PSA of HRV was assessed for 1 block of 18 trials. The dependent variables were analyzed in separate 2-Practice Condition: (proactive, retroactive) by 2-Retention test: (immediate, delayed) ANOVA, with repeated measures on the last variable. Similar to acquisition, the LF/HF ratio was assessed as 1 block of 18 trials with the LF/HF ratios averaged in a 1-Block ANOVA by 2-Practice condition: (proactive, retroactive).

For the Braille Prime retention phase, RS and PSA of HRV was assessed for 1 block of 18 trials. A 2-Practice condition: (proactive, retroactive) by 1-Block ANOVA was used.

All statistical analyses were conducted using Statistica version 7.0 by StatSoft Inc. A significance level of $p < .05$ was accepted for all statistical analyses. A Tukey's HSD post-hoc analysis was used to analyze any statistically significant interactions.

CHAPTER 5: RESULTS

5.1 RECALL SUCCESS (RS)

5.1.1 Acquisition

The means for RS for all experimental conditions are displayed in Table 4. There was a significant main effect for Block, F (7, 154) = 62.64, p = .000, η_p^2 = .74, and Practice Condition, F (1, 22) = 126.55, p = .000, η_p^2 = .85. The main effects were superseded by a Block by Practice Condition interaction, F (7, 154) = 57.07, p = .000, η_p^2 = .72 (see Appendix C1). The post hoc analysis for the Block by Practice Condition interaction indicated superior RS by the proactive condition on blocks 1-7 compared to the retroactive condition, with no between condition differences on block 8 (see Figure 14; Appendix D1). The proactive condition demonstrated RS near ceiling levels throughout the acquisition period. In the retroactive condition, Block 1 was performed with less RS than Blocks 3 to 8; Block 2 was performed with less RS than Blocks 4 to 8; Block 3 was performed with less RS than Blocks 5 to 8; Block 4 was performed with less RS than Blocks 5 to 8; and Block 5 was performed with less RS than Blocks 7 and 8. Recall success frequency for each experimental stimuli during acquisition is displayed in Table 9. When evaluating individual stimuli, the proactive condition demonstrated more frequent RS on 2-keystroke, 3-keystroke, and 4-keystroke sequences, compared to the retroactive condition.

5.1.2 Immediate and Delayed English Prime Retention Test

The means for RS for all experimental conditions are displayed in Table 4. There was a significant main effect for Retention Test, F (1, 22) = 8.34, p= .009, η_p^2 = .27, with the delayed English prime retention test (*M* = .56, *SD* = .33) being performed with less RS compared to the immediate English prime retention test (*M* = .61, *SD* = .32). The main effect for Practice Condition, F (1, 22) = 14.75, p = .001, η_p^2 = .40 was also statistically significant where the proactive condition (*M* = .39, *SD* = .30) demonstrated less RS compared to the retroactive condition (*M* = .78, *SD* = .19; see Figure 14; Appendix D2). However, the Retention Test by Practice Condition interaction, F (1, 22) = 1.15, p = .294 failed to reach statistical significance (see Appendix C2). Recall success frequency for each experimental stimuli during retention is displayed in Table 10. When evaluating individual stimuli, the retroactive condition demonstrated more frequent RS on 2-keystroke, 3-keystroke, and 4-keystroke sequences, compared to the proactive condition.

5.1.3 Immediate and Delayed Braille Prime Retention Test

The means for RS for all experimental conditions are displayed in Table 4. There was a significant main effect for Retention Test, F (1, 22) = 5.31, p = .016, η_p^2 = .19. The post hoc analysis indicated the delayed Braille prime retention test (*M* = .55, *SD* = .32) was performed with less RS compared to the immediate Braille prime retention test (*M* = .60, *SD* = .34). The main effect for Practice Condition, F (1, 22) = 13.47, p = .002, η_p^2 = .38 was also statistically significant where the proactive condition (*M* = .38, *SD* = .32) demonstrated less RS compared to the retroactive condition (*M* = .77, *SD* = .19) during retention. However, the Retention Test by Practice Condition interaction, F (1, 22) = .017, p = .897 failed to reach statistical significance (see Figure 14; Appendix C3; Appendix D3). Recall success frequency for each experimental stimuli during retention is displayed in Table 10. When evaluating individual stimuli, the retroactive condition demonstrated more frequent RS on 2-keystroke, 3-keystroke, and 4-keystroke sequences, compared to the proactive condition.

5.2 STUDY TIME (ST)

5.2.1 Acquisition

The means for ST for all experimental conditions are displayed in Table 5. There was a significant main effect for Block, F (7, 154) = 36.27, p = .000, η_p^2 = .62, and Practice Condition, F (1, 22) = 49.31, p = .000, η_p^2 = .69. The main effects were superseded by a Block by Practice Condition interaction, F (7, 154) = 15.24, p = .000, η_p^2 = .41 (see Appendix C1). The post hoc analysis of the Block by Practice Condition interaction indicated less ST by the proactive condition on blocks 1-4 compared to the retroactive condition, with no between condition differences on blocks 5-8 (see Figure 15; Appendix D4). There were no within condition differences for the proactive condition. In the retroactive condition, Block 1 was performed with longer ST than Blocks 2 to 8; Block 2 was performed with longer ST than Blocks 4 to 8; Block 3 was performed with longer ST than Blocks 5 to 8; and Block 4 was performed with longer ST than Blocks 7 and 8.

5.3 REACTION TIME (RT)

5.3.1 Acquisition

The means for RT for all experimental conditions are displayed in Table 6. There was a significant main effect for Block, F (7, 154) = 6.19, p = .000, η_p^2 = .22, and Practice Condition, F (1, 22) = 80.42, p = .000, η_p^2 = .79. The main effects were superseded by a Block by Practice Condition interaction, *F* (7, 154) = 5.19, *p* = .000, η_p^2 = .19 (see Appendix C1). The post hoc analysis for the Block by Practice Condition interaction indicated the proactive condition demonstrated shorter RT on all acquisition blocks (blocks 1-8) compared to the retroactive condition (see Figure 16; Appendix D5). There were no within condition differences for the proactive condition. In the retroactive condition, Block 1 was performed with longer RT than Blocks 7 and 8; Block 2 was performed with longer RT than Blocks 5 to 8; Block 3 was performed with longer RT than Blocks 6 to 8; and Block 4 was performed with longer RT than Block 7.

5.3.2 Immediate and Delayed English Prime Retention Test

The means for RT for all experimental conditions are displayed in Table 6. The ANOVA failed to show a main effect for Retention Test, *F* (1, 22) = .08, *p* = .777, Practice Condition, *F* (1, 22) = .02, p = .885 or Retention Test by Practice Condition interaction, *F* (1, 22) = .81, *p* = .377 (see Figure 16; Appendix C2).

5.4 RELATIVE CHANGE IN HEART RATE VARIABILITY (HRV)

5.4.1 Acquisition

A preliminary reliability test was performed to assess the internal consistency of the baseline LF/HF ratios obtained from the participants prior to each testing session, Cronbach α = .704, indicating the baseline LF/HF measurements were reliable. The means for HRV for all experimental conditions are displayed in Table 7. The ANOVA failed to reveal a main effect for Block, *F* (7, 154) = 1.35, *p* = .231, Practice Condition, *F* (1, 22) = 2.58, *p* = .122 or a Block by Practice Condition interaction, *F* (7, 154) = 1.09, *p* = .374 (see Figure 17; Appendix C1).

5.4.2 Immediate and Delayed English Prime Retention Test

The means for HRV for all experimental conditions are displayed in Table 7. There was a significant main effect for Practice Condition, F (1, 22) = 10.22, p = .004, η_p^2 = .32. The post hoc analysis of the main effect for Practice condition indicated the retroactive condition (M = 1.23, SD = .75) demonstrated a lower increase LF/HF ratio compared to the proactive condition (M = 2.53, SD = 1.50) during the English prime retention test. However, the main effect for Retention Test, F (1, 22) = .24, p = .632 and the Retention Test by Practice Condition interaction, F (1, 22) = .12, p = .737 failed to reach statistical significance (see Figure 17; Appendix C2; Appendix D6).

5.4.3 Immediate and Delayed Braille Prime Retention Test

The means for HRV for all experimental conditions are displayed in Table 7. There was a significant main effect for Practice Condition, F (1, 22) = 10.33, p = .004, η_p^2 = .32. The post hoc analysis of the main effect for condition indicated the retroactive condition (M = 1.51, SD = .80) demonstrated a lower increase LF/HF ratio compared to the proactive condition (M = 2.65, SD = 1.51) during the Braille prime retention test. However, the main effect for Retention Test, F (7, 154) = .06, p = .810, and the Retention Test by Practice Condition interaction, F (1, 22) = .07, p = .793 failed to reach statistical significance (see Figure 17; Appendix C3; Appendix D7).

Pearson correlation comparisons were used to measure the strength of relationships between physiological response (PSA of HRV) and perceived cognitive effort (NASA TLX). There was however no significant relationship between the PSA of HRV measures and NASA TLX measures for this study (See Appendix E1).

5.5 MODIFIED NASA TASK LOAD INDEX

5.5.1 Acquisition

The means for NASA TLX for all experimental conditions are displayed in Table 8. The ANOVA showed a main effect for Practice Condition, F (1, 22) = 34.79 p = .000, η_p^2 = .61. The post hoc analysis of the main effect for Practice Condition indicated the retroactive condition (M = 30.17, SD = 11.52) reported more invested effort compared to the proactive condition (M = 9.17, SD = 4.41) during acquisition (see Figure 18; Appendix C1; Appendix D8).

5.5.2 Immediate and Delayed English Prime Retention Test

The means for NASA TLX for all experimental conditions are displayed in Table 8. There was a significant main effect for Practice Condition, F (1, 22) = 5.49, p = .029, η_p^2 = .20. The post hoc analysis of the main effect for Practice condition indicated the retroactive condition (M = 23.38, SD = 10.62) reported less invested effort compared to the proactive condition (M = 33.0, SD = 10.90) during the English prime retention (see Figure 18; Appendix C2; Appendix D8). However, the main effect for Retention Test, F (1, 22) = 1.23, p = .279 and the Retention Test by Practice Condition interaction, F (1, 22) = 3.61, p = .071 failed to reach statistical significance.

5.5.3 Immediate and Delayed Braille Prime Retention Test

The means for NASA TLX for all experimental conditions are displayed in Table 8. The ANOVA failed to show a main effect for Practice Condition, F (1, 22) = 1.52, p =

.231, Retention Test, F (1, 22) = .80, p = .382, and Retention Test by Practice Condition interaction, F (1, 22) = .03, p = .867 (see Figure 18; Appendix C3; Appendix D8).

CHAPTER 6: DISCUSSION

6.1 INTRODUCTION TO THE DISCUSSION

The purpose of this study was to extend existing motor learning research by examining the differential impact of proactive and retroactive practice conditions on the physiological responses of the learner. Patterson and Lee (2005, 2008, 2010) and Richardson and Lee (1999) established the superior learning benefits produced by acquiring motor skills through retroactive practice conditions. To our knowledge, the current experiment was the first to use HRV, a physiological measure, to capture cognitive effort as a method of gauging learning during a proactive/ retroactive practice condition schedule. For this study, participants were required to learn a novel motor task, which consisted of learning a secondary language. Braille was chosen as the template for the novel sequence since it possessed similar characteristics to the secondary languages chosen in previous research; Patterson and Lee, (2005, 2008, 2010) used PDA characters and Richardson and Lee (1999) used manual gestures of the American Sign Language. PDA characters, sign language and Braille all possess varying levels of conceptual compatibility across the different English-script translations. Since most individuals have very little experience with Braille, it provided a level of novelty that was a required asset to this experiment. Braille was transferred into a serial motor response to be performed as a key-pressing task.

Experiment 1 was designed to determine the level of conceptual compatibility between Braille-sequences and their associated English-script pairs. Conceptual compatibility was operationally defined as the degree of spatial and motor relatedness between an English-script and the corresponding Braille-sequence (Patterson & Lee, 2005). Participants were required to enter a series of motor sequences between 1 and 5 keystrokes in length that they perceived to best represent the corresponding English-script primes. The results of Experiment 1 confirmed the majority of the English-script Braille-sequence pairings were enigmatic, suggesting a low level of conceptual compatibility between these English-scripts and their corresponding Braille-sequences. Pairs that were deemed to possess a low level of conceptual compatibility were included as potential stimuli for Experiment 2.

For Experiment 2, we predicted that participants in the retroactive condition would display inferior recall success during the acquisition period and then superior recall success during the retention period compared to the proactive condition since it has been argued that retroactive participants engage in more meaningful practice during acquisition that leads to superior learning. (Patterson & Lee, 2005, 2008, 2010; Richardson & Lee, 1999). Both of these predictions were supported by our results. For the HRV analyses it was predicted that participants in the retroactive condition would display a higher increase in LF/HF ratio compared to the proactive condition during acquisition and a lower increase in LF/HF ratio compared to the proactive condition during retention (Pomeranz, et al., 1985; Rivecourt, Kuperus, Post, & Mulder, 2008, Wilson, Smith, & Holmes, 2007). Based on physiological measures, an increase in cognitive effort is supported by an increase in sympathetic stimulation, we interpret this increase in SNS activity through HRV, specifically an increase in LF/HF ratio. Based on previous literature it has been suggested that the retroactive condition is more cognitively demanding, therefore we would expect to see an increase in LF/HF ratio during acquisition and a decrease in effort as the individual reaches automaticity of the skill, however, until now, it has not been measured. The results did not support our prediction for HRV during acquisition. However, the results did support our prediction for HRV during the retention period. Specifically, it was found that there was in an increase in cognitive effort from both conditions during acquisition and as a function of learning, the retroactive participants invested significantly less cognitive effort during retention compared to the proactive participants.

Importantly, the results of the Experiment 2 extend our current theoretical understandings of the learning benefits of a retroactive practice condition for the acquisition of motor skills. The interpretation of our results is subcategorized into two main sections; behavioural measures and physiological responses. Each experimental prediction is examined individually within their respective section.

6.2 BEHAVIOURAL MEASURES

According to our first experimental prediction, participants in the retroactive condition would display inferior recall success compared to the proactive condition during the acquisition period. The RS results of our experiment support our first prediction, such that, during acquisition the retroactive condition demonstrated inferior RS scores compared to participants in the proactive condition who performed near ceiling levels. However, participants within the retroactive condition demonstrated gradual improvements in RS over the course of the acquisition period, such that both groups were equated at the end of acquisition. During the acquisition period, participants in the retroactive condition were required to attempt the Braille-sequence, even though the sequence was essentially guessed on the first trial of each pairing. These participants needed to retrieve a motor plan of what the sequence might be, execute that plan through corresponding key presses, and then assess their accuracy based on the augmented information provided to them after their motor attempt. Poor RS scores exhibited by the retroactive participants during the early stages of acquisition reflect the cognitively effortful nature of this practice condition.

After the first block of trials, the retroactive participants were required to retrieve the information from memory. As one retrieves memories, an increased sensitivity in the synapses used to execute that task occurs which aids in the retrieval of a particular memory at a later point (Bjork, 1988). Low RS scores demonstrated by the retroactive participants were attributed to the intervening practice trials between the presentation of the augmented information and the opportunity provided to the learner to use that information. The participants in the retroactive condition were required to perform 17 different sequences before that information could be utilized. This resulted in a temporary negative impact on the retroactive participant's performance during the early stages of acquisition. However, this effect had positive influences on learning since it cognitively engaged the learner in a more active process of retrieving information and contributed to the enhancement of error detection and correction (Oliveira, Correa, Gimenez, Basso, & Tani, 2009). This finding was consistent with past research conducted by Patterson and Lee (2005, 2008, 2010) and Richardson and Lee (1999).

As the acquisition period continued and retroactive participants RS improved, their ST decreased, to a point that reached similar levels to the proactive participants within the last four blocks of practice. The proactive participants had a significantly lower RT than the retroactive participants during every block in acquisition. For the proactive condition, the task-related information was provided to the participant prior to a motor response and used to assist in performance immediately after. Since the information was utilized so quickly, the response required to complete the motor task was readily available in participants working memory (Kalat, 2004). As a result, the cognitive processes involved in facilitating learning, mainly retrieval, were avoided by the low demands on working memory during practice, subsequently impacting performance in the retention period. This could explain why the dependent variables RS, RT, and ST, did not change during the acquisition period for the proactive condition. Recall success scores were near ceiling, very little time was spent studying the associated pairs, and their reaction to stimuli was quick. The participants moved quickly from one trial to the next, only stimulating their working memory. Thus, the proactive condition did not practice retrieval of information. Without retrieval practice, a motor memory for the correct response was not established. These results are consistent with Patterson and Lee (2005, 2008, 2010) and Richardson and Lee (1999). The NASA TLX questionnaire results confirmed the proactive condition not only performed superiorly to the retroactive condition based on the objective measures, but also self-reported their interaction with the task less demanding compared to the retroactive condition during the acquisition period.

Our second experimental prediction stated that participants in the retroactive condition would display superior RS compared to the proactive condition during the retention period. The RS results of our experiment support our second prediction. Retention was evaluated by two types of tests; English prime retention test and Braille prime retention test, both administered at two different time points; an immediate retention period and 24 hour delayed retention period. The English prime retention test seen in Figure 12, required participants to provide the correct Braille-sequence after being prompted by an English prime consistent with the acquisition period. The second retention test was designed to eliminate the potential for a specificity of practice effect (Magill, 2001). The English prime retention test procedure was similar to the retroactive condition, potentially providing a practice advantage to the retroactive condition when tested in this manner. Therefore, the Braille prime retention test was created so that all participants would have to retrieve the information in an equated manor, such that when the Braille-sequence was displayed, they would be required to provide the correct English-script.

As predicted, the proactive condition demonstrated decreased RS during the immediate and delayed retention periods on both the English prime retention test and the Braille prime retention test compared to their acquisition performance, reflecting the performance learning paradox. This paradox states that changes during practice reflect temporary influences on performance and does not reflect learning of the motor skill (Schmidt & Lee, 2011). Although the proactive participants performed superior to the retroactive condition during acquisition they did not learn the English-script Braille-sequence pairings nearly as well as the retroactive participants. We attributed this to the fact that the processes that promote learning, such as the act of retrieving stored information, were not practiced since augmented information was provided prior to attempting a response which eliminated the necessity for memory retrieval (Bjork, 1988;

Richardson & Lee, 1999). Consequently, performance deficits occurred when this information was no longer available in retention.

We suggest that the low investment of cognitive effort required to perform well during acquisition is the reason that the proactive participants demonstrated poor retention scores. The opposite was found for the participants in the retroactive condition who demonstrated similar RS performances during the immediate and delayed retention periods on both the English prime retention test and the Braille prime retention test compared to their performance at the end of the acquisition period, and superior to the proactive condition. This occurred since the retroactive condition was designed to provide the learner with more opportunities to retrieve the information resulting in heightened cognitive effort. Retrieving information is considered a cognitively demanding process that like any other skill becomes more efficient and effective from practice conditions that promote this process (Bjork, 1988). Participants in the retroactive condition invested considerable effort cognitively to complete the motor task during the acquisition period since task-related information was not provided prior to attempting a response.

The NASA TLX questionnaire showed the retroactive condition perceived their interaction with the task as demanding. When augmented information was removed during retention, retroactive participants utilized the same process practiced during acquisition to retrieve the required information from memory. The performance of the retroactive condition also reflected the performance learning paradox since performance scores indicated by RS was low during acquisition in contrast to the high scores obtained during retention verifying that the retroactive participants learned the English-script

Braille-sequence pairings. Therefore, independent of retention test type or time, the retroactive condition demonstrated superior learning compared to the proactive group. These results are consistent with Patterson and Lee (2005, 2008, 2010) and Richardson and Lee (1999).

Participants in the retroactive condition displayed superior learning during retention compared to the proactive participants, as demonstrated by their superior RS scores. The current experiment suggests those in the retroactive condition learned the English-script Braille-sequence pairings, supporting the retroactive condition to be a superior teaching technique from a behavioural standpoint. This was further supported by the retroactive conditions physiological responses which are analyzed below.

6.3 PHYSIOLOGICAL RESPONSES

Our third experimental prediction stated that during acquisition, the LF/HF ratio would be directly proportional to the cognitive effort utilized by the participant. That is, the retroactive condition was expected to invest higher cognitive effort during acquisition, resulting in a higher increase in LF/HF ratio compared to the proactive condition (Pomeranz, et al., 1985; Rivecourt, Kuperus, Post, & Mulder, 2008, Wilson, Smith, & Holmes, 2007). The HRV results of our experiment do not support our third prediction. We suggest that this is reflective of the cognitively demanding nature of the task. Proactive and retroactive conditions displayed an increase in LF/HF ratio during acquisition reflecting an increase in cognitive effort. For the proactive condition, the process of activating and constantly using working memory, although not beneficial to learning, was still a cognitively effortful process (Hansen, Johnsen, & Thayer, 2003). It was a novel task for all participants and the fact that they were participating and engaging in the task may have accounted for this similarity.

Our final experimental prediction stated that during the retention portion of the experiment, the LF/HF ratio would be directly proportional to the cognitive effort utilized by the participants as a function of experimental condition. That is, the retroactive condition was expected to invest lower cognitive effort during retention compared to the proactive condition, resulting in a lower increase in LF/HF ratio (Pomeranz, et al., 1985; Rivecourt, Kuperus, Post, & Mulder, 2008, Wilson, Smith, & Holmes, 2007). The HRV results of our experiment did support this prediction. The proactive condition demonstrated a significantly higher increase LF/HF ratio during both immediate and delayed English prime retention test and Braille prime retention test compared to the retroactive condition. We suggest that the lower increase in LF/HF ratio displayed by the retroactive participants is reflective of minimal cognitive effort required to execute a learned motor task.

Neural structures associated with executive functions required for memory and learning are located in the prefrontal cortical areas of the brain (Hansen, Johnsen, & Thayer, 2003). When task demands are non-routine, executive functions stimulate descending sympathetic and parasympathetic pathways connected to the heart passing on this message. The result is a change in HRV. An increase in LF/HF ratio suggests a person is cognitively involved (Wilson, Smith, & Holmes, 2007). In contrast, a decrease in LF/HF ratio indicates that a person is not as cognitively involved (Wilson, Smith, & Holmes, 2007). The physiological results of the present thesis suggest the retroactive condition invested less cognitive effort compared to the proactive condition in the retention phase of the experiment. As the participants learned the task, we expected to see a decrease in cognitive effort since they had become more efficient at the task. It's suggested that the proactive participants did not learn as much as the retroactive condition evidenced by their mistakes in the retention period. We argue the proactive participants did not engage in retrieval practice during acquisition and therefore did not establish a motor memory for the experimental stimuli. Since proactive participants were unable to successfully engage in the process of retrieval, the proactive participants self-reported the retention period to be more cognitively demanding then the participants in the retroactive condition, reflected by their increased LF/HF ratio.

Our results have extended our understanding of the mechanisms underlying the cognitive processes engaged during proactive and retroactive practice. The current experiment suggests the retroactive condition displayed lower increase in LF/HF during the retention period indicating decreased cognitive effort as a function of learning. The retroactive conditions combined superior RS scores and lower increase in LF/HF ratio during retention, support the retroactive condition to be a superior teaching technique from both a behavioural and physiological standpoint.

6.4 APPLICATION OF THE FINDINGS

The current study presents important information about the connection between the cognitive demands and behavioural indicators of learning to the actual physiological response of that learner. To the best of our knowledge, this was the first experiment to use HRV, a physiological measure, to capture cognitive effort as a method of gauging motor learning during a proactive/ retroactive practice condition. Based on the results, HRV is suggested to be a reliable physiological measure of learning a motor task and optimal for use during the retention period, since data during acquisition was indiscernible irrespective of the condition. However, the NASA TLX provided accurate insight to the learners perceived level of difficulty and interaction with the task. This subjective measure mirrored and supported the objective measures (study time, reaction time, and recall success) throughout the learning process for both the retroactive and proactive conditions. Therefore, the most feasible and efficient technique for teachers and coaches based on the results was the NASA TLX. By utilizing the optimal measurement tool for each learning environment can further improve current teaching techniques. Now teachers can measure the engagement of learners to ensure the practice paradigms used are optimally engaging individuals to be cognitively involved for increased retention.

6.5 LIMITATIONS

Heart rate variability is a very sensitive measure with great capabilities and many limitations. Since it is so sensitive, there is a very small population of participants that qualify. For this study alone, the exclusion criteria included; individuals younger than 18 and older than 35, left handed individuals, individuals with prior experience or knowledge of Braille, high level athletes, and individuals with heart or anxiety disorders. With such a specific population, the findings of this study are only applicable to a small population. Further research should be extended to special or excluded groups (athletes, older adults, or high anxiety individuals). Another suggested area to investigate is an extended practice period to ensure automaticity of the motor skill.

6.6 SUMMARY

In summary, participants in the retroactive condition displayed superior learning during retention compared to the proactive participants. This was further supported by the retroactive participants lower increase in LF/HF ratio during retention, indicating a lower level of cognitive effort being applied to execute learned motor skills. Our study found similar results with respect to motor learning then extended it to the effects of these practice conditions on the physiological responses of the learner and their perception of that task with the NASA TLX questionnaire.

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Sequence	**Script**	**x=right**	**Number Correct**
7415	R	0	0
72	1	.17	1
71852	Y	0	0
1852	0	0	0
785	D	0	0
48	I	0	0
4152	“	0	0
4	,	0	0
78	C	0	0
742	2	0	0
7185	N	0	0
152	)	0	0
75	E	0	0
1	‘	.17	1
7412	V	0	0
74	B	0	0
782	3	0	0
7852	4	0	0
745	H	.33	2
7485	G	0	0
12	-	.17	1
485	J	0	0
7182	X	.33	2
45	;	0	0
752	5	0	0
715	O	0	0
7152	Z	0	0
42	?	0	0
415	!	0	0
7418	P	0	0
482	9	0	0
41	:	0	0
74185	Q	.17	1
412	(	0	0
7452	8	.17	1
452	.	0	0
4185	T	0	0
718	M	0	0
7482	6	0	0
71	K	0	0
712	U	0	0
4852	W	0	0
418	S	0	0

Table 1. Descriptive statistics for Experiment 1.

Time	Condition	Sex	Retention Order	Condition	Sex	Retention Order
9:00	Proactive	Female	AB	Proactive	Male	AB
	Proactive	Female	BA	Retroactive	Male	BA
	Retroactive	Female	BA	Retroactive	Male	AB
10:30	Proactive	Female	BA	Proactive	Male	BA
	Retroactive	Female	AB	Proactive	Male	AB
	Retroactive	Female	BA	Retroactive	Male	AB
12:00	Proactive	Female	AB	Proactive	Male	BA
	Retroactive	Female	AB	Proactive	Male	AB
	Retroactive	Female	BA	Retroactive	Male	BA
13:30	Proactive	Female	AB	Proactive	Male	BA
	Proactive	Female	BA	Retroactive	Male	BA
	Retroactive	Female	AB	Retroactive	Male	AB

Table 2. Distribution of participants (Experiment 2).

Trial Number	Acquisition	English Prime Retention A	Braille Prime Retention A	English Prime Retention B	Braille Prime Retention B
1	1	?	.	“	K
2	.	M	B	K	.
3	“	“	“	O	G
4	C	1	!	G	B
5	2	O	1	C	!
6	N	6	W	!	Z
7	B	E	O	Z	C
8	G	2	6	M	S
9	O	W	C	?	N
10	Z	K	S	W	?
11	?	.	G	2	M
12	!	G	K	1	“
13	E	B	M	6	1
14	M	!	?	B	O
15	6	Z	N	.	W
16	K	C	2	N	E
17	W	S	Z	E	2
18	S	N	E	S	6

Table 3. Sequence orders of experimental stimuli for Experiment 2.

Condition	n	Block 1 M (SD)	Block 2 M (SD)	Block 3 M (SD)	Block 4 M (SD)	Block 5 M (SD)	Block 6 M (SD)	Block 7 M (SD)	Block 8 M (SD)	EPRI M (SD)	BPRI M (SD)	EPRD M (SD)	BPRD M (SD)
Proactive	12	.95 (.09)	.99 (.02)	1.00 (.00)	.98 (.03)	.97 (.04)	.99 (.02)	1.00 (.02)	.99 (.03)	.42 (.31)	.49 (.30)	.35 (.29)	.36 (.31)
Retroactive	12	.01 (.02)	.13 (.11)	.25 (.21)	.37 (.22)	.58 (.24)	.66 (.21)	.74 (.26)	.79 (.25)	.80 (.21)	.79 (.20)	.77 (.21)	.75 (.18)

Table 4. Descriptive statistics for Recall Success (Experiment 2).

Condition	n	Block 1 M (SD)	Block 2 M (SD)	Block 3 M (SD)	Block 4 M (SD)	Block 5 M (SD)	Block 6 M (SD)	Block 7 M (SD)	Block 8 M (SD)
Proactive	12	1830 (535)	1370 (407)	1294 (423)	1209 (425)	1113 (255)	1043 (249)	990 (185)	971 (145)
Retroactive	12	5211 (1862)	3913 (1484)	3179 (1157)	2688 (858)	2183 (623)	1846 (795)	1683 (685)	1372 (295)

Table 5. Descriptive statistics for Study Time (ms) (Experiment 2).

Condition	n	Block 1 M (SD)	Block 2 M (SD)	Block 3 M (SD)	Block 4 M (SD)	Block 5 M (SD)	Block 6 M (SD)	Block 7 M (SD)	Block 8 M (SD)	EPRI M (SD)	EPRD M (SD)
Proactive	12	513 (220)	381 (177)	339 (146)	329 (158)	300 (124)	302 (130)	279 (113)	260 (97)	3620 (1555)	3287 (1569)
Retroactive	12	4885 (2116)	6027 (3494)	5656 (2825)	4669 (2018)	4143 (1322)	3849 (1518)	3102 (1270)	3239 (1532)	3286 (1441)	3458 (1543)

Table 6. Descriptive statistics for Reaction Time (ms) (Experiment 2).

Condition	n	Block 1 M (SD)	Block 2 M (SD)	Block 3 M (SD)	Block 4 M (SD)	Block 5 M (SD)	Block 6 M (SD)	Block 7 M (SD)	Block 8 M (SD)	EPRI M (SD)	BPRI M (SD)	EPRD M (SD)	BPRD M (SD)
Proactive	12	2.35 (1.33)	2.24 (1.69)	2.95 (2.63)	2.63 (1.95)	2.69 (2.03)	2.68 (1.72)	2.33 (1.47)	2.09 (1.29)	2.65 (1.68)	2.74 (1.42)	2.42 (1.36)	2.55 (1.65)
Retroactive	12	1.15 (.76)	1.38 (1.29)	1.55 (1.25)	1.46 (1.25)	1.53 (1.10)	1.92 (1.69)	1.90 (1.91)	1.66 (1.61)	1.25 (.50)	1.51 (.86)	1.20 (.96)	1.52 (.77)

Table 7. Descriptive statistics for Heart Rate Variability (Experiment 2).

		Acqu	EPRI	BPRI	EPRD	BPRD
Condition	**n**	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)
Proactive	12	9.17 (4.41)	32.33 (8.69)	33.08 (10.66)	33.67 (13.12)	31.67 (14.13)
Retroactive	12	30.17 (11.52)	25.92 (10.53)	28 (10.42)	20.83 (10.72)	25.92 (11.61)

Table 8. Descriptive statistics for NASA Task Load Index Questionnaire (Experiment 2).

		Block 1		**Block 2**		**Block 3**		**Block 4**		**Block 5**		**Block 6**		**Block 7**		**Block 8**		
Keystroke	English script	Pro	Retro	Pro	Retro	Pro	Retro	Pro	Retro	Pro	Retro	Pro	Retro	Pro	Retro	Pro	Retro	***Mean for script***
2	1	1.00	0.00	1.00	0.17	1.00	0.42	1.00	0.50	1.00	0.58	1.00	0.67	1.00	0.92	1.00	0.83	***0.76***
2	C	1.00	0.00	1.00	0.08	1.00	0.42	1.00	0.50	1.00	0.75	1.00	0.75	1.00	0.83	0.92	0.75	***0.75***
2	B	1.00	0.08	1.00	0.25	1.00	0.33	1.00	0.58	1.00	0.92	1.00	0.92	1.00	0.83	1.00	0.92	***0.80***
2	?	0.92	0.00	1.00	0.08	1.00	0.17	1.00	0.42	0.92	0.42	1.00	0.42	1.00	0.50	1.00	0.67	***0.66***
2	E	0.92	0.00	1.00	0.08	1.00	0.08	1.00	0.17	1.00	0.17	0.92	0.33	1.00	0.58	1.00	0.67	***0.62***
2	K	1.00	0.00	1.00	0.00	1.00	0.08	1.00	0.33	1.00	0.58	1.00	0.75	1.00	0.75	1.00	0.92	***0.71***
	Mean	***0.97***	***0.01***	***1.00***	***0.11***	***1.00***	***0.25***	***1.00***	***0.42***	***0.99***	***0.57***	***0.99***	***0.64***	***1.00***	***0.74***	***0.99***	***0.79***	
3	.	0.92	0.00	1.00	0.17	1.00	0.25	1.00	0.33	1.00	0.42	0.92	0.50	1.00	0.58	1.00	0.67	***0.67***
3	2	0.92	0.00	1.00	0.08	1.00	0.17	0.92	0.00	0.92	0.42	1.00	0.50	1.00	0.42	1.00	0.67	***0.63***
3	O	0.92	0.00	0.92	0.08	1.00	0.42	0.83	0.50	1.00	0.92	1.00	0.75	0.92	0.67	1.00	0.83	***0.73***
3	!	1.00	0.00	1.00	0.17	1.00	0.17	1.00	0.25	0.92	0.33	1.00	0.67	1.00	0.75	1.00	0.75	***0.69***
3	M	1.00	0.00	1.00	0.17	1.00	0.08	1.00	0.08	1.00	0.58	1.00	0.50	1.00	0.67	1.00	0.75	***0.68***
3	S	0.83	0.00	1.00	0.00	1.00	0.08	1.00	0.42	0.92	0.42	1.00	0.75	1.00	0.67	1.00	0.67	***0.67***
	Mean	***0.93***	***0.00***	***0.99***	***0.11***	***1.00***	***0.19***	***0.96***	***0.26***	***0.96***	***0.51***	***0.99***	***0.61***	***0.99***	***0.63***	***1.00***	***0.72***	
4	"	1.00	0.00	1.00	0.42	1.00	0.58	1.00	0.67	0.92	0.83	1.00	0.92	1.00	1.00	1.00	0.92	***0.83***
4	N	0.92	0.00	1.00	0.00	1.00	0.17	1.00	0.50	1.00	0.50	1.00	0.67	1.00	0.83	1.00	0.75	***0.71***
4	G	1.00	0.00	1.00	0.17	1.00	0.33	1.00	0.58	1.00	0.67	1.00	0.83	1.00	1.00	0.92	1.00	***0.78***
4	Z	1.00	0.00	1.00	0.17	1.00	0.25	1.00	0.17	1.00	0.50	1.00	0.58	1.00	0.67	1.00	0.75	***0.69***
4	6	0.92	0.00	0.92	0.00	1.00	0.08	0.92	0.17	1.00	0.50	1.00	0.50	1.00	0.75	1.00	0.67	***0.65***
4	W	0.92	0.00	1.00	0.17	1.00	0.42	1.00	0.50	0.92	1.00	1.00	0.83	1.00	1.00	1.00	1.00	***0.80***
	Mean	***0.96***	***0.00***	***0.99***	***0.15***	***1.00***	***0.31***	***0.99***	***0.43***	***0.97***	***0.67***	***1.00***	***0.72***	***1.00***	***0.88***	***0.99***	***0.85***	

Table 9. Recall success frequency for each experimental stimuli during acquisition (Experiment 2).

		EPRI		EPRD			BPRI		BPRD		
Keystroke	English script	Pro	Retro	Pro	Retro	***Mean for script***	Pro	Retro	Pro	Retro	***Mean for script***
2	1	0.50	0.92	0.50	0.92	***0.71***	0.50	0.92	0.50	0.92	***0.71***
2	C	0.42	0.92	0.42	0.83	***0.65***	0.33	0.92	0.33	0.92	***0.63***
2	B	0.58	0.92	0.58	1.00	***0.77***	0.50	1.00	0.50	1.00	***0.75***
2	?	0.33	0.58	0.25	0.75	***0.48***	0.33	0.50	0.25	0.33	***0.35***
2	E	0.33	0.58	0.25	0.67	***0.46***	0.42	0.58	0.25	0.58	***0.46***
2	K	0.58	0.92	0.42	0.92	***0.71***	0.42	1.00	0.50	1.00	***0.73***
	Mean	***0.46***	***0.81***	***0.40***	***0.85***		***0.42***	***0.82***	***0.39***	***0.79***	
3	.	0.25	0.58	0.17	0.33	***0.33***	0.25	0.67	0.25	0.42	***0.40***
3	2	0.25	0.67	0.25	0.75	***0.48***	0.33	0.67	0.17	0.58	***0.44***
3	O	0.50	0.92	0.33	0.75	***0.63***	0.50	0.92	0.42	1.00	***0.71***
3	!	0.25	0.67	0.08	0.67	***0.42***	0.33	0.58	0.17	0.50	***0.40***
3	M	0.33	0.75	0.25	0.67	***0.50***	0.25	0.67	0.33	0.50	***0.44***
3	S	0.25	0.75	0.25	0.75	***0.50***	0.42	0.83	0.42	0.75	***0.60***
	Mean	***0.31***	***0.72***	***0.22***	***0.65***		***0.35***	***0.72***	***0.29***	***0.63***	
4	"	0.75	0.92	0.50	0.92	***0.77***	0.50	0.92	0.42	0.92	***0.69***
4	N	0.42	0.92	0.33	0.83	***0.62***	0.42	0.75	0.25	0.75	***0.54***
4	G	0.33	1.00	0.42	0.92	***0.67***	0.33	1.00	0.33	1.00	***0.67***
4	Z	0.42	0.83	0.33	0.50	***0.52***	0.50	0.67	0.42	0.67	***0.56***
4	6	0.25	0.58	0.25	0.67	***0.44***	0.33	0.67	0.17	0.67	***0.46***
4	W	0.83	1.00	0.75	1.00	***0.90***	0.58	1.00	0.75	1.00	***0.83***
	Mean	***0.50***	***0.88***	***0.43***	***0.81***		***0.44***	***0.83***	***0.39***	***0.83***	

Table 10. Recall success frequency for each experimental stimuli during retention (Experiment 2).

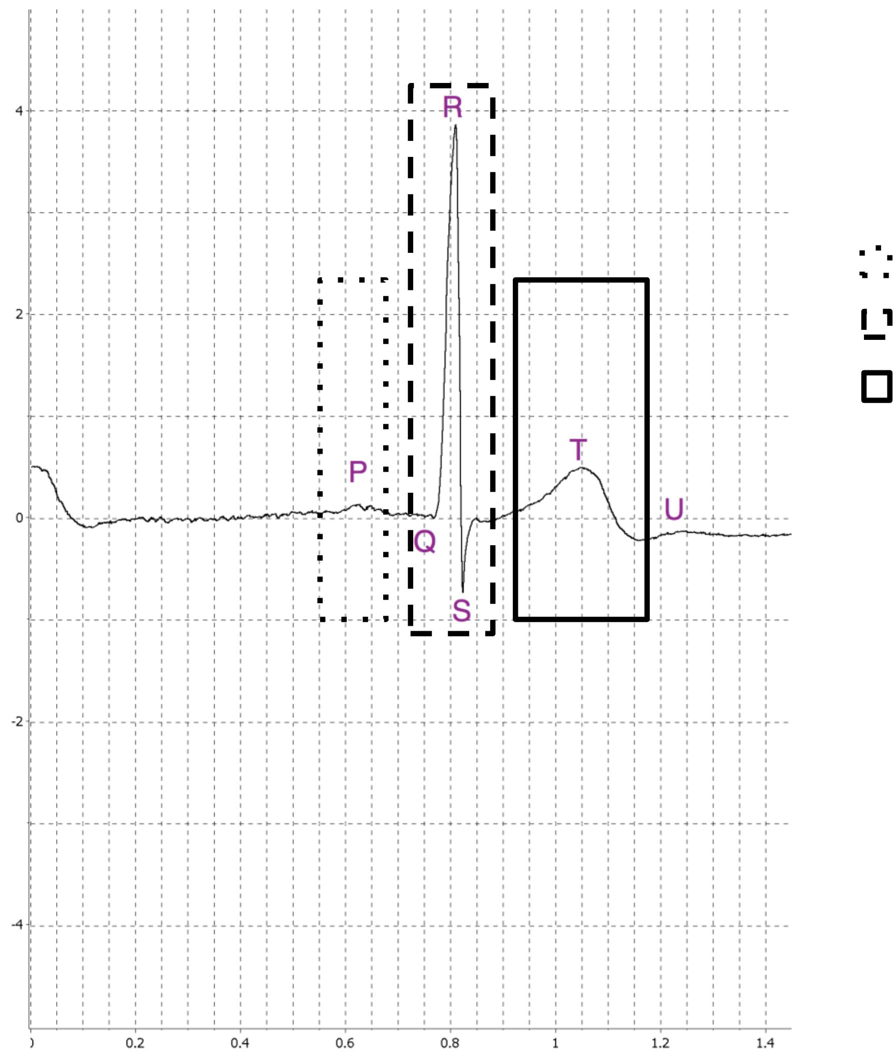


Figure 1. Illustration of participants ECG outlining the QRS complex and R-spike used for PSA of HRV (sample of participant data).

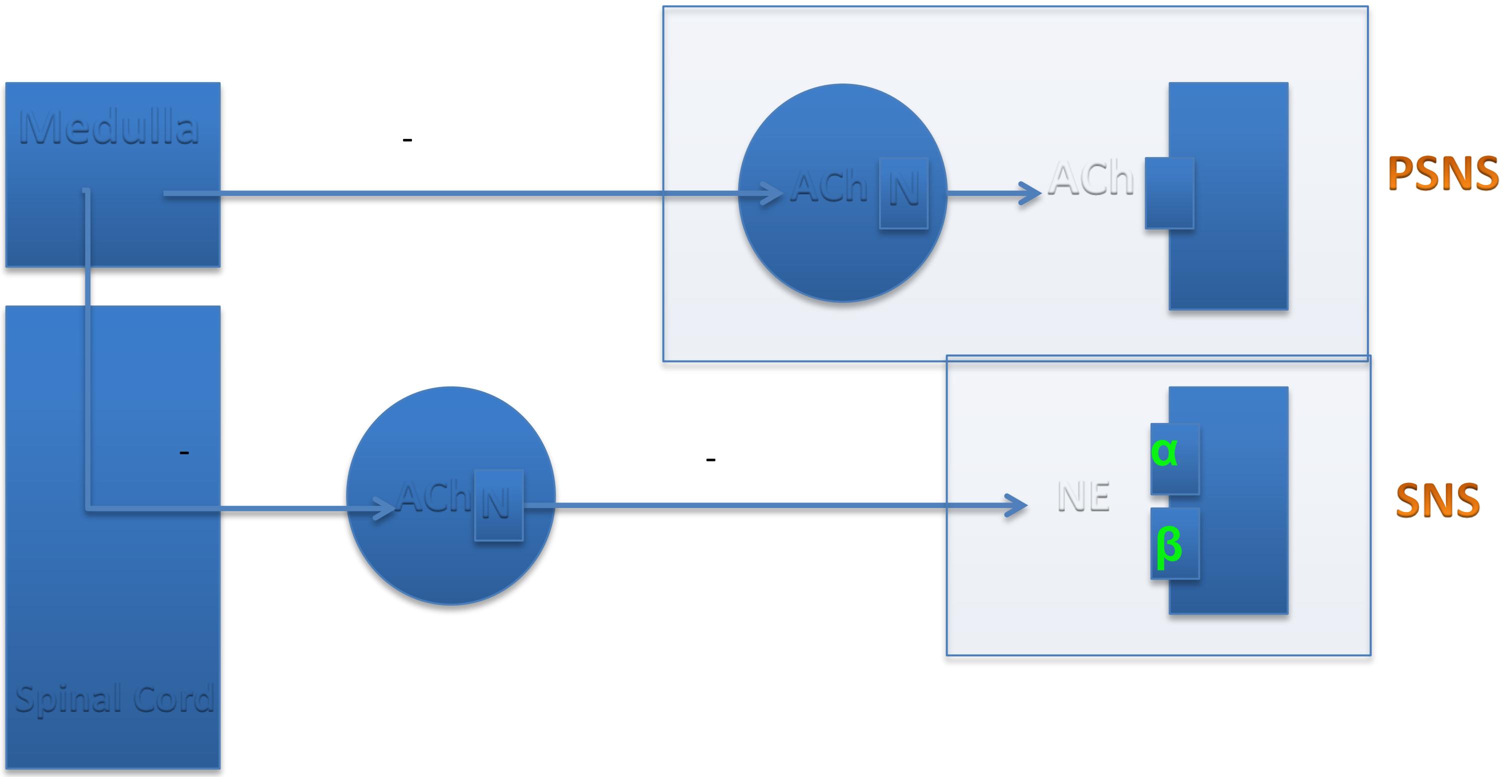


Figure 2. Sympathetic and parasympathetic synapse pathways from the cerebellum to the heart.

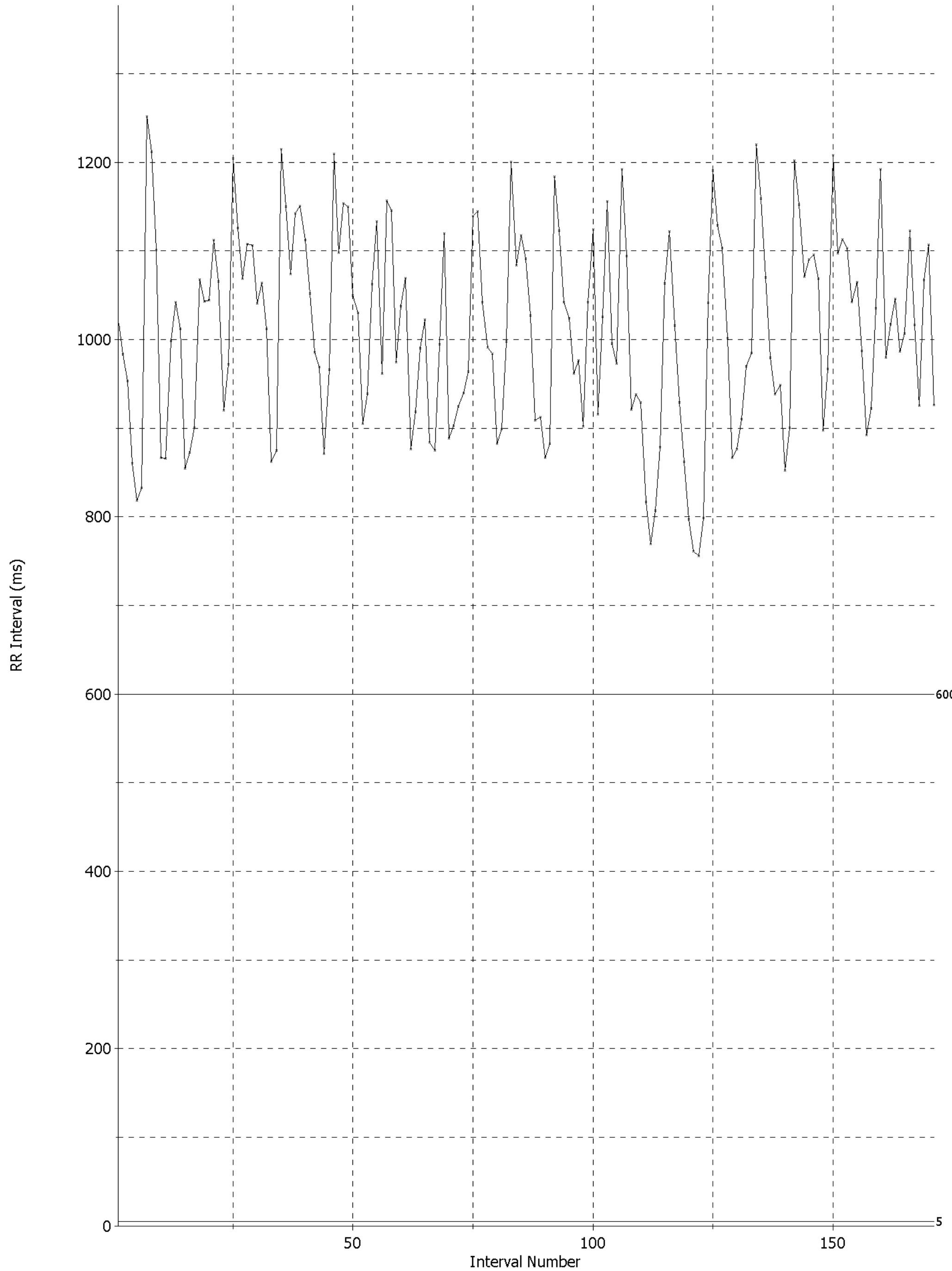


Figure 3. Illustration of a tachogram (sample of participant data).

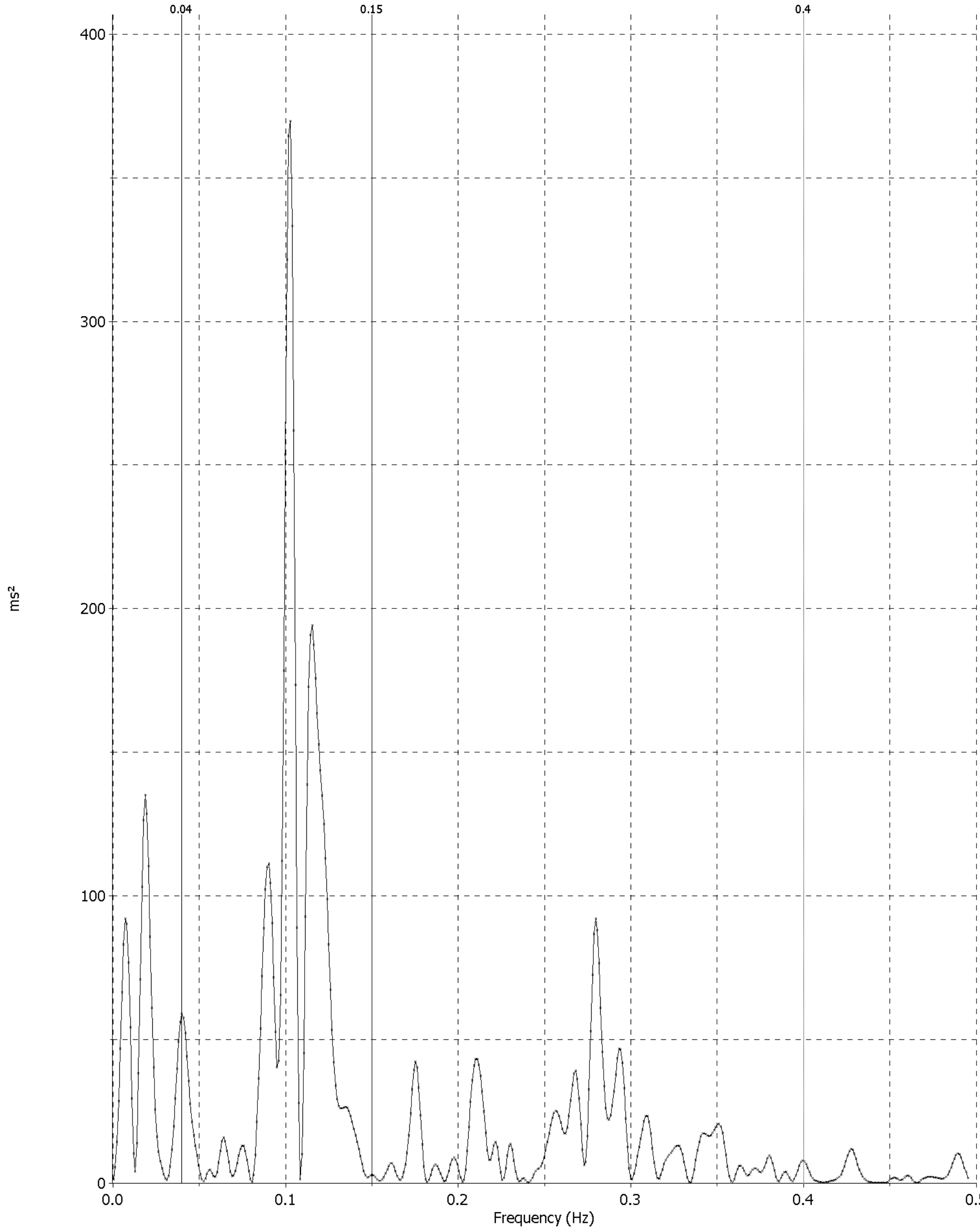
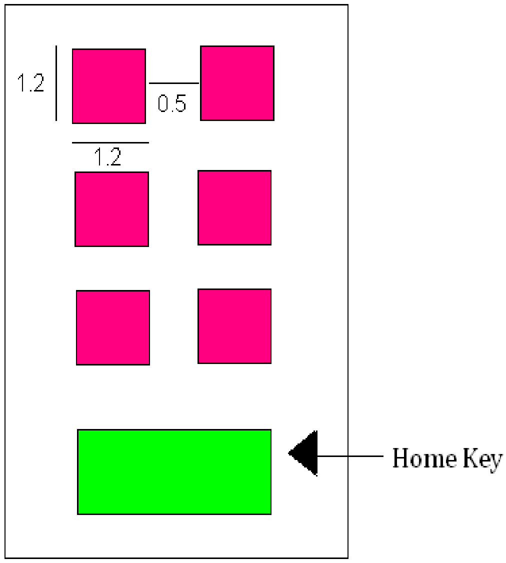


Figure 4. Illustration of a power spectrum. The low frequency (LF) ranges from 0.04 to 0.15 Hz and the high frequency (HF) ranges from 0.15 to 0.4 Hz (sample of participant data).



Pink keys (above) vs. 6 blank Braille cell dots (below).

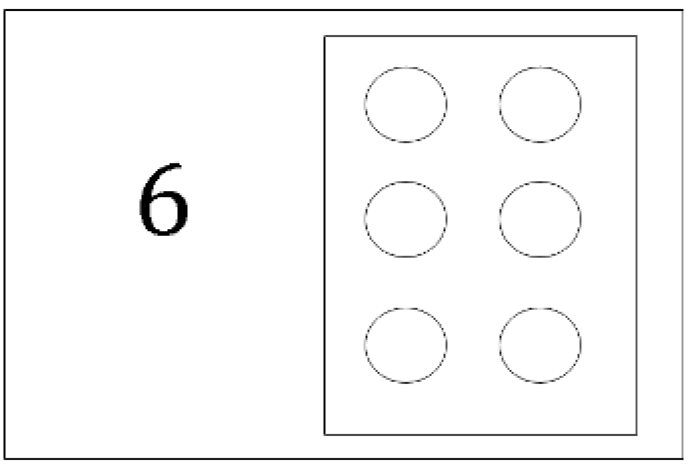


Figure 5. Representation of number pad used to enter responses in comparison to the Braille cell.

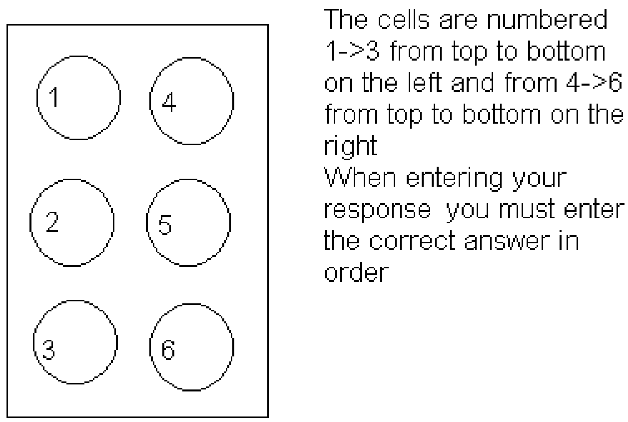


Figure 6. Instruction screen designed to inform participants the correct numbering of the Braille cell.

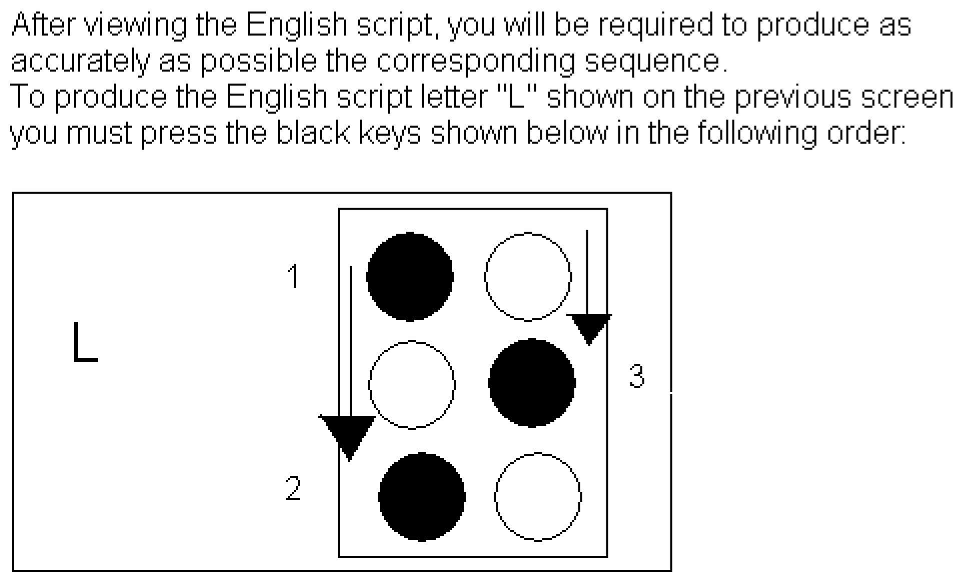


Figure 7. Instruction screen designed to explain to participants how to properly enter sequences.

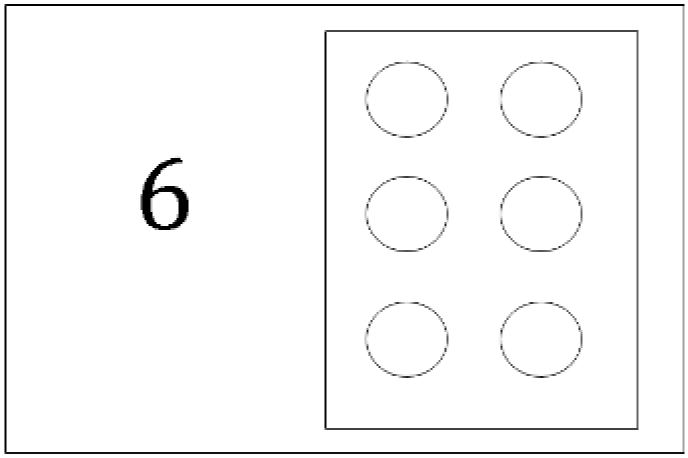
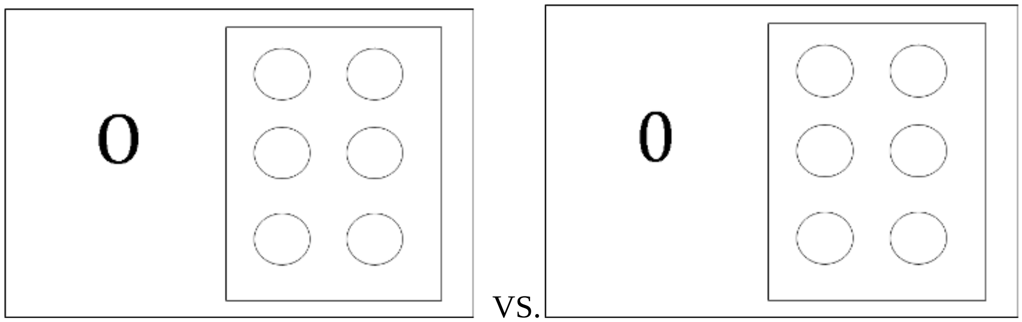
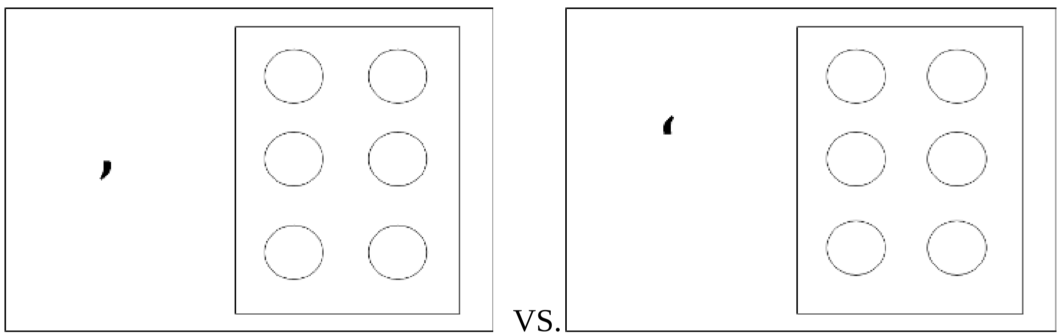


Figure 8. Example of an English-script prime without its associated Braille-sequence.



On the left is the letter o and on the right is the number 0.



On the left is a comma and on the right is the single quote.

Figure 9. English-script Braille-sequence pairs “O”, “0”, “single quote”, “comma” comparison, to display difficulty distinguishing primes when associated Braille-sequence is not provided.

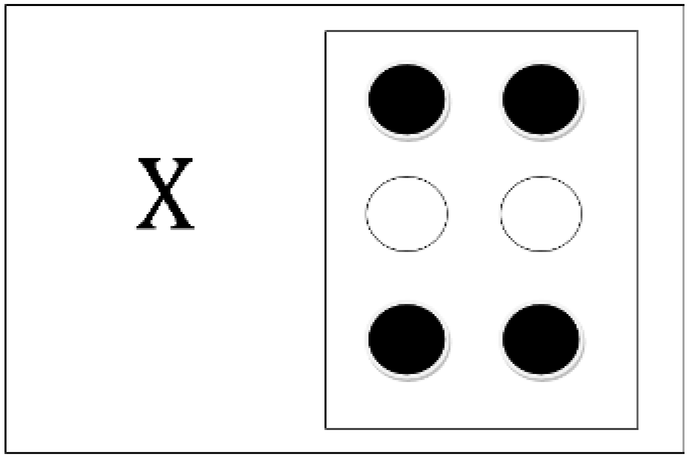


Figure 10. English-script Braille-sequence pair “X”.

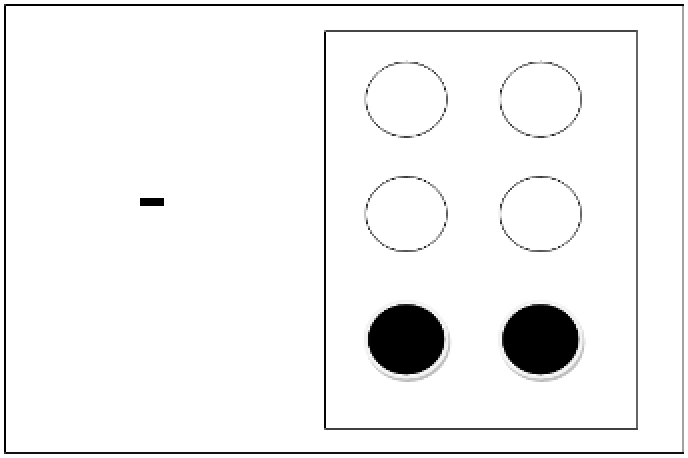


Figure 11. English-script Braille-sequence pair “dash”.

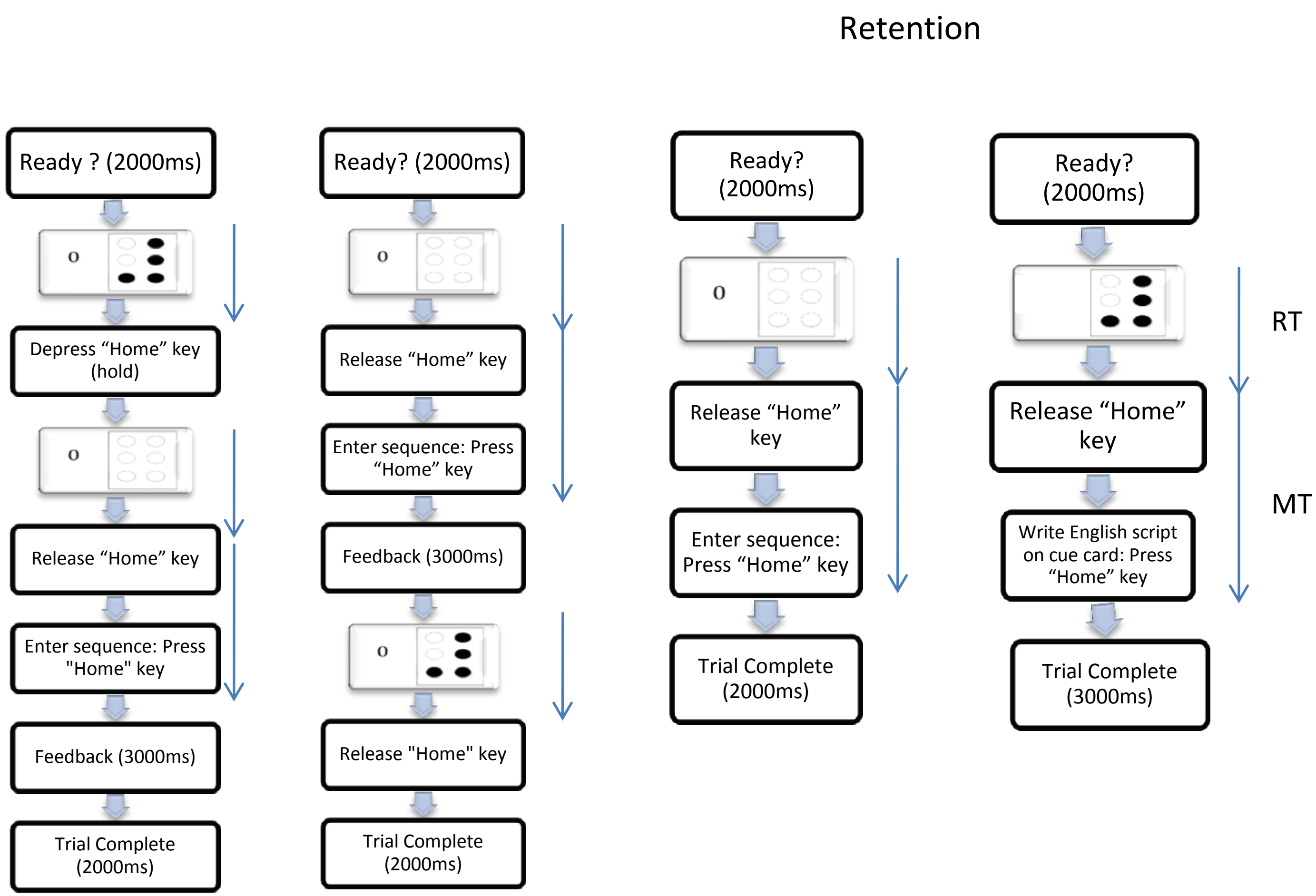


Figure 12. Illustration of the timeline of events for trial procedures in the proactive and retroactive conditions (Experiment 2).

ST=Study time
RT=Reaction time
MT=Movement time

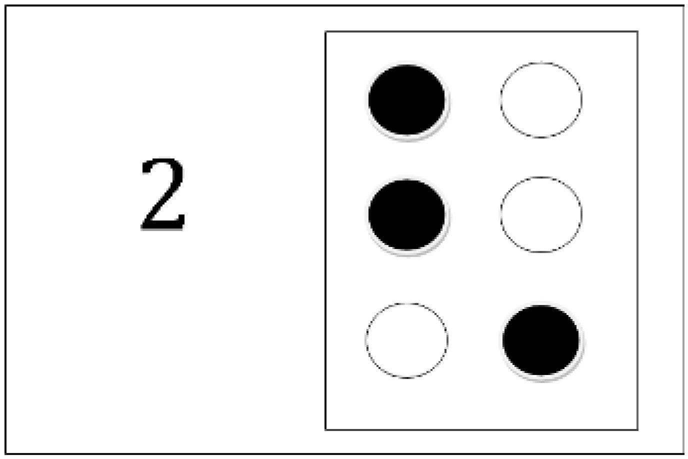


Figure 13. Example of an English-script prime with its associated Braille-sequence.

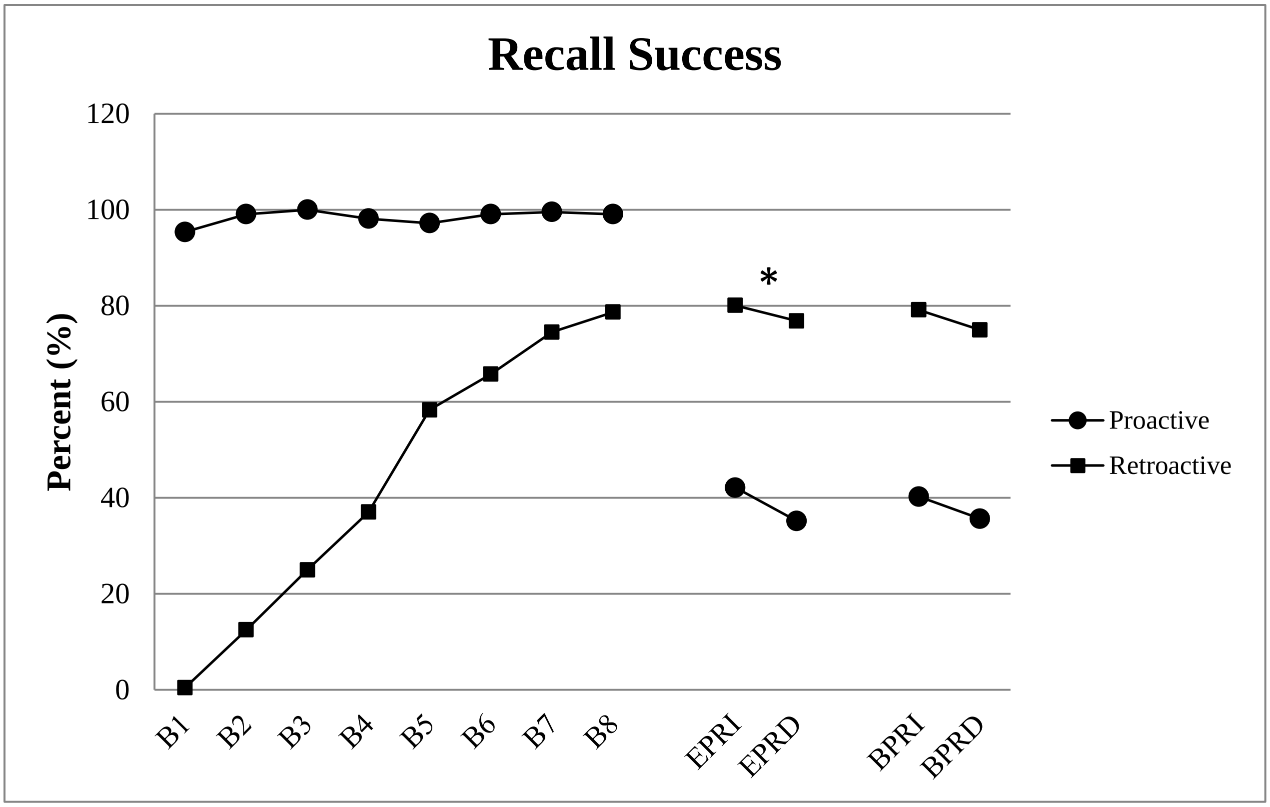


Figure 14. Recall Success for all experimental conditions for acquisition (blocks 1 to 8), English prime retention (immediate [15-min] and delayed [24-hr]), and Braille prime retention (immediate [15-min] and delayed [24-hr]).

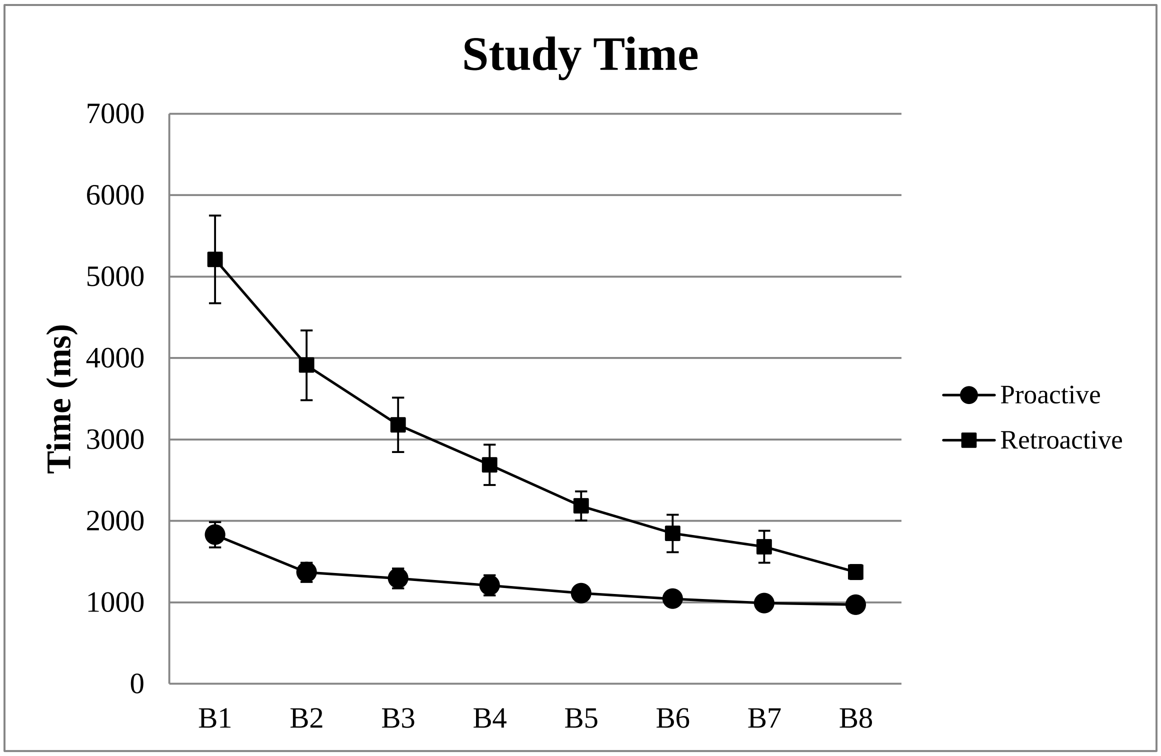


Figure 15. Study Time for all experimental conditions for acquisition (blocks 1 to 8).

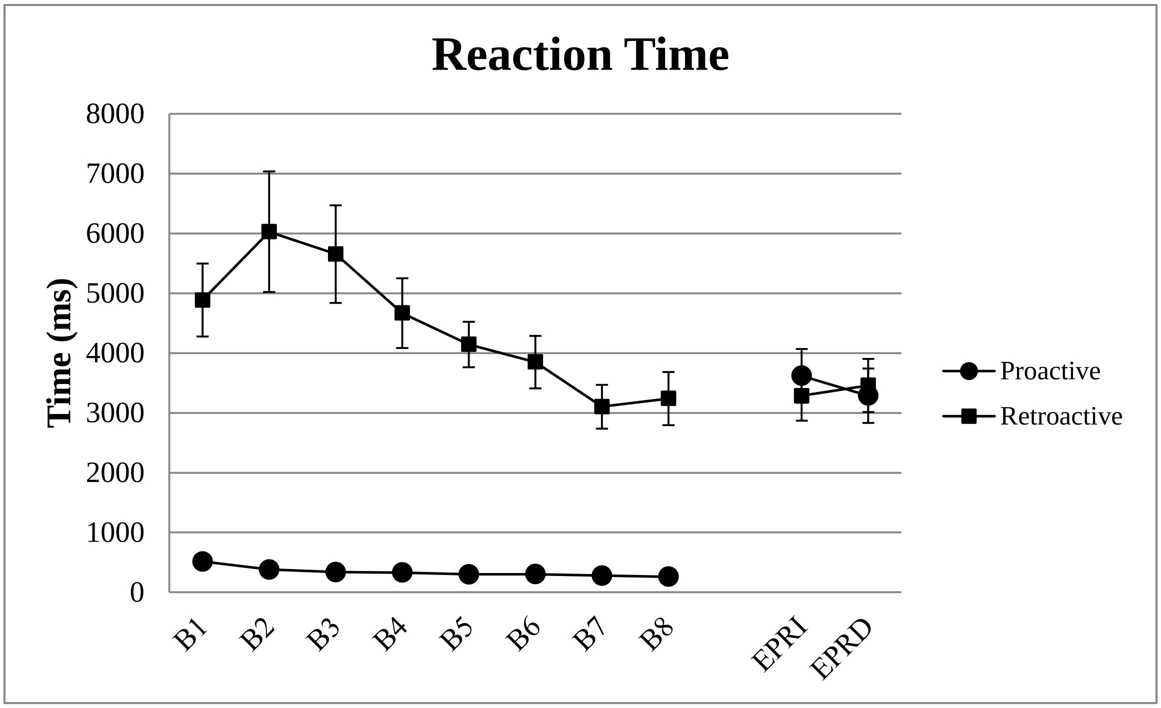


Figure 16. Recation Time for all experimental conditions for acquisition (blocks 1 to 8), and English prime retention (immediate [15-min] and delayed [24-hr]).

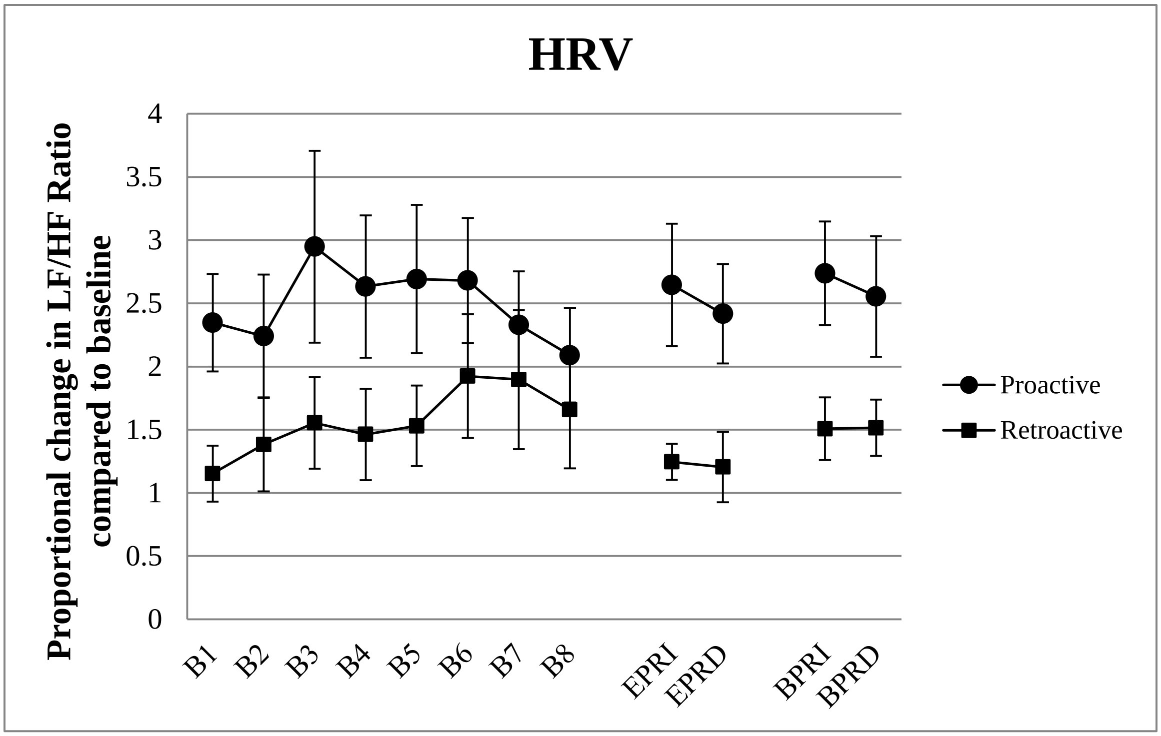


Figure 17. HRV for all experimental conditions for acquisition (blocks 1 to 8), English prime retention (immediate [15-min] and delayed [24-hr]), and Braille prime retention (immediate [15-min] and delayed [24-hr]).

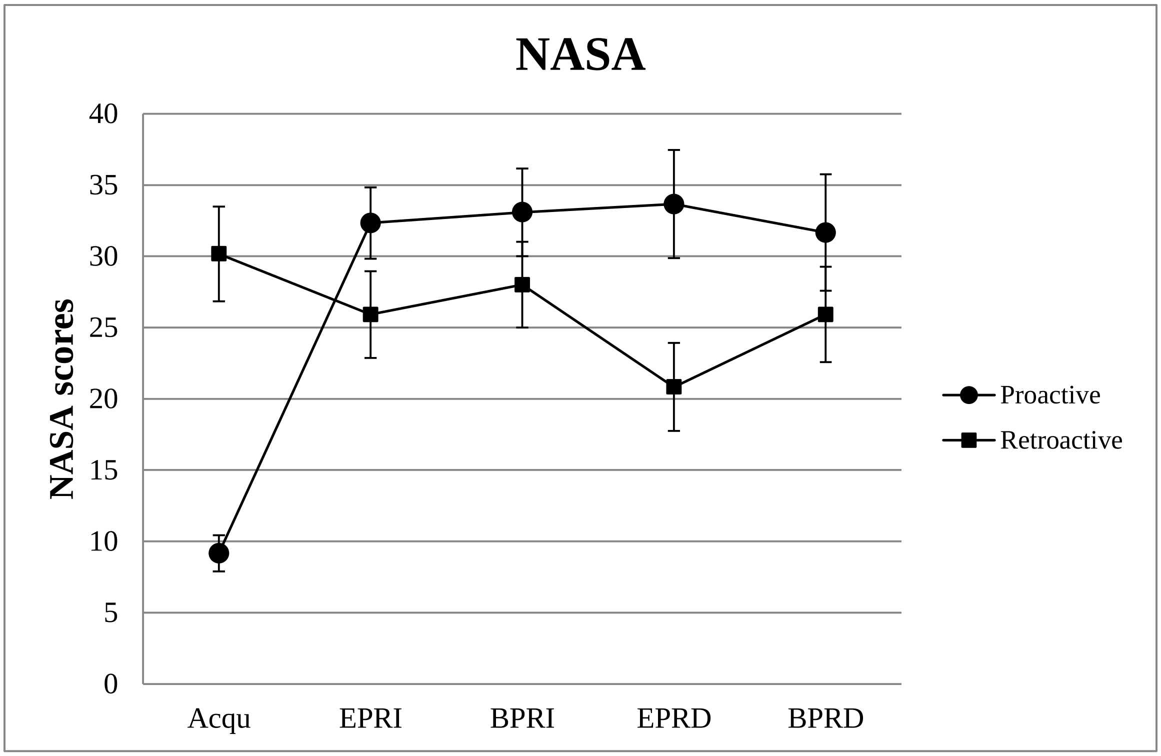
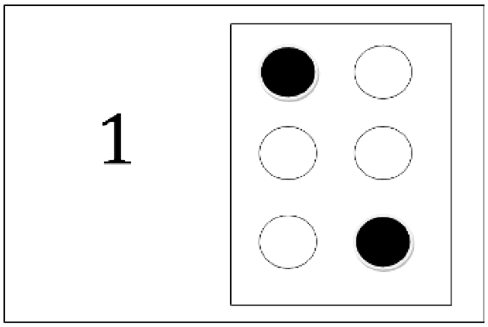


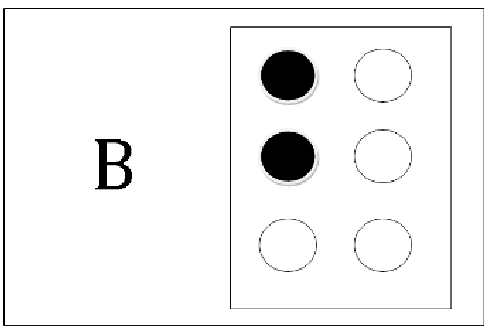
Figure 18. NASA Task Load Index scores for all experimental conditions for acquisition (blocks 1 to 8), English prime retention (immediate [15-min] and delayed [24-hr]), and Braille prime retention (immediate [15-min] and delayed [24-hr]).

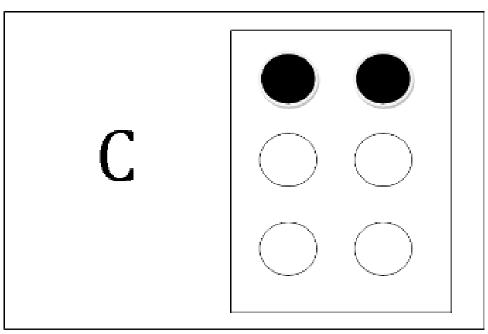
Appendix A

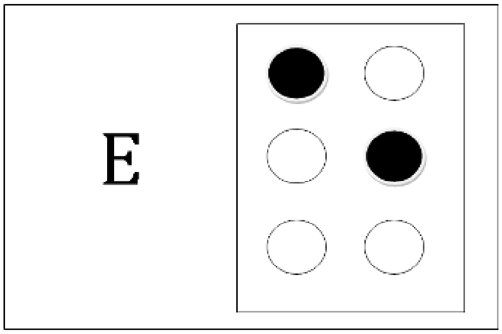
Experimental Stimuli

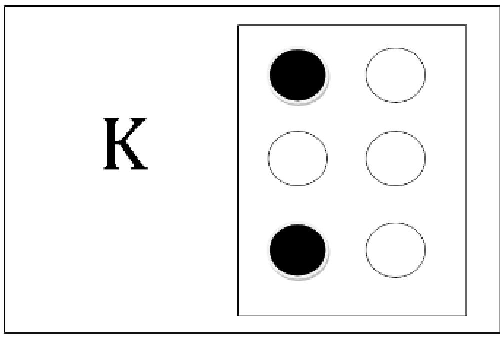
2-Keystroke sequences

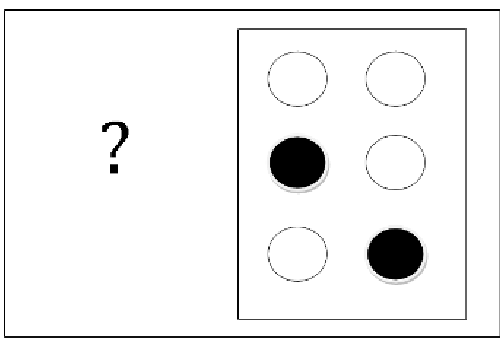




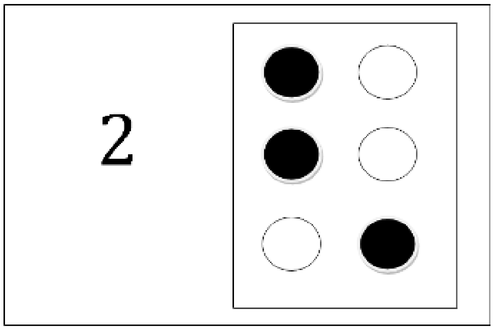


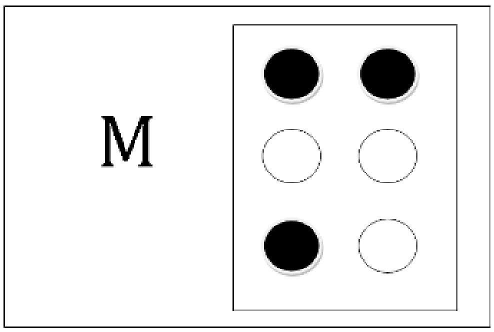

E

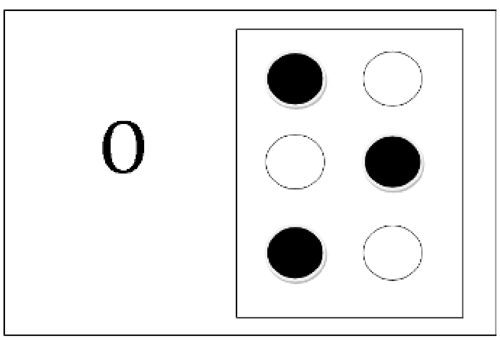

K

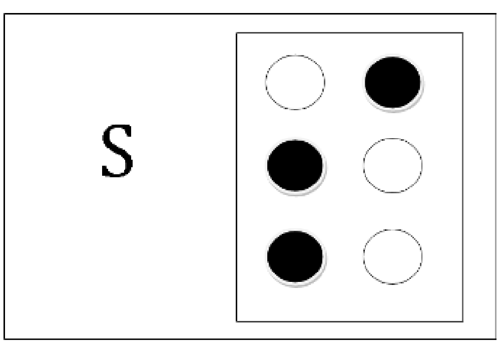

?

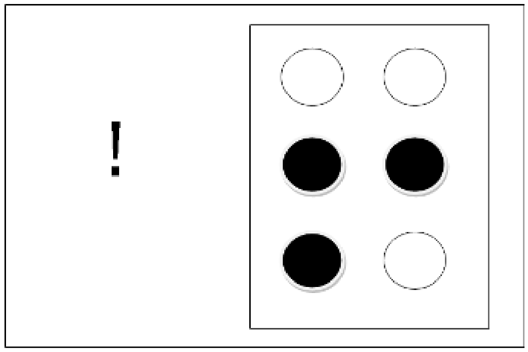
3-Keystroke sequences

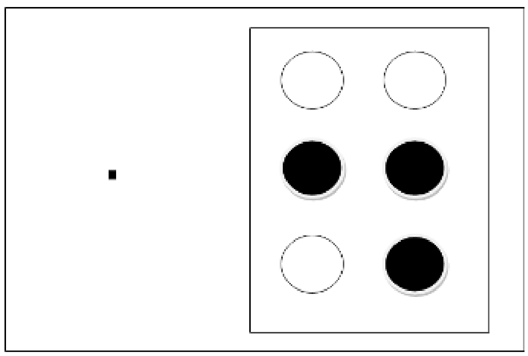




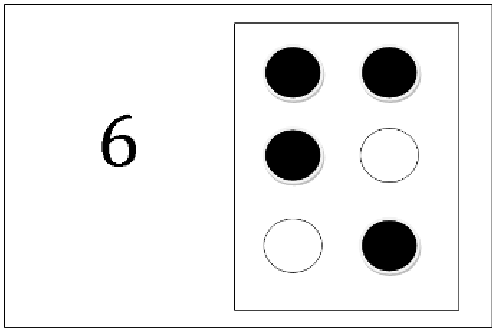


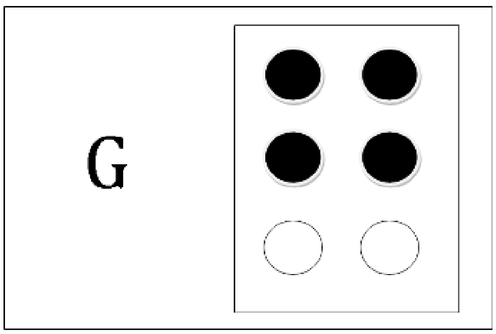


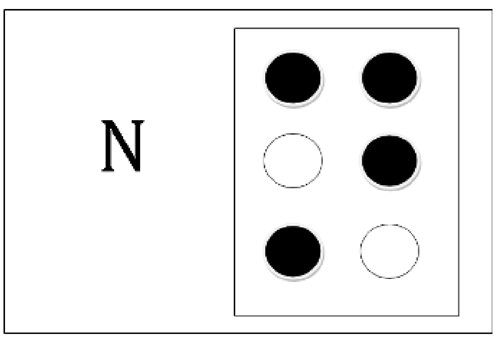


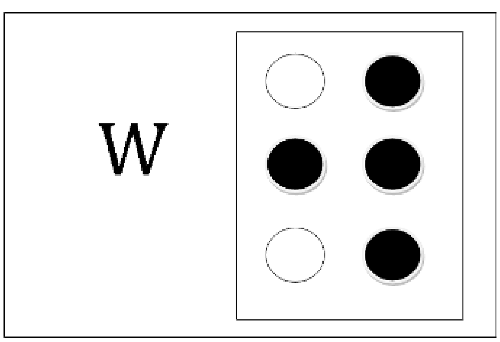


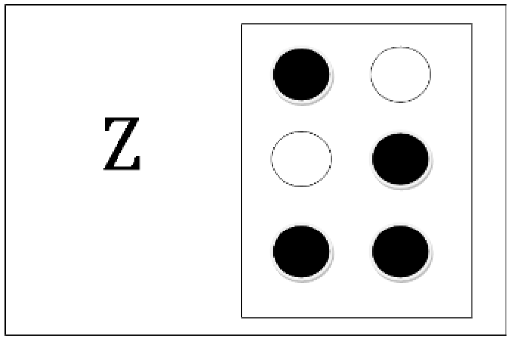
4-Keystroke sequences

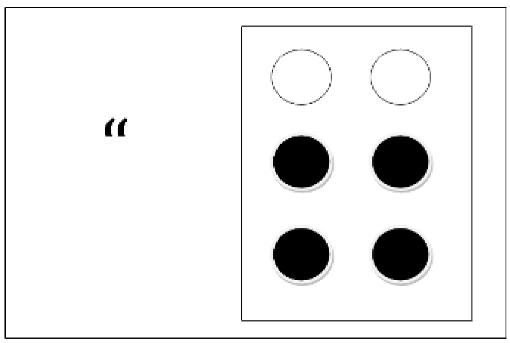









Z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Appendix B

NASA Task Load Index (Hart & Staveland, 1988)

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

Appendix C1

Analysis of Variance for Acquisition (Experiment 2)

Measure	Condition	Block	Block X Condition
Recall Success	F (1, 22) = 126.55	F (7, 154) = 62.64	F (7, 154) = 57.07
	p = .000*	p = .000*	p = .000*
Study Time	F (1, 22) = 49.31	F (7, 154) = 36.27	F (7, 154) = 15.24
	p = .000*	p = .000*	p = .000*
Reaction Time	F (1, 22) = 80.42	F (7, 154) = 6.19	F (7, 154) = 5.19
	p = .000*	p = .000*	p= .000*
Heart Rate	F (1, 22) = 2.58	F (7, 154) = 1.35	F (7, 154) = 1.09
Variability	p = .122	p = .231	p = .374
	F (1, 22) = 34.79		
NASA TLX	p = .000*		

*p < .05.

Appendix C2

Analysis of Variance for Immediate and Delayed English Prime Retention

(Experiment 2)

Measure	**Condition**	**Test**	**Test X Condition**
Recall Success	*F* (1, 22) = 14.75	*F* (1, 22) = 8.34	*F* (1, 22) = 1.15
	p = .001*	*p*= .009*	*p* = .294
Reaction Time	*F* (1, 22) = .02	*F* (1, 22) = .08	*F* (1, 22) = .81
	p = .885	*p* = .777	*p* = .377
Heart Rate	*F* (1, 22) = 10.22	*F* (1, 22) = .24	*F* (1, 22) = .12
Variability	*p* = .004*	*p* = .632	*p* = .737
	F (1, 22) = 5.49	*F* (1, 22) = 1.23	*F* (1, 22) = 3.61
NASA TLX	*p* = .029*	*p* = .279	*p* = .071

*$p < .05$.

Appendix C3

Analysis of Variance for Immediate and Delayed Braille Prime Retention

(Experiment 2)

Measure	Condition	Test	Test X Condition
Recall Success	F (1, 22) = 13.47	F (1, 22) = 5.31	F (1, 22) = .017
	p = .002*	p = .016*	p = .897
Heart Rate	F (1, 22) = 10.33	F (7, 154) = .06	F (1, 22) = .07
Variability	p = .004*	p = .810	p = .793
	F (1, 22) = 1.52	F (1, 22) = .80	F (1, 22) = .03
NASA TLX	p = .231	p = .382	p = .867

*p < .05.

Appendix D1

Post Hoc Table for Recall Success Acquisition (Experiment 2)

Condition		Block	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
			0.95	0.99	1.00	0.98	0.97	0.99	1.00	0.99	0.01	0.13	0.25	0.37	0.58	0.66	0.74	0.79
1	P	B1		0.99985	0.99752	1.00000	1.00000	0.99985	0.99931	0.99980	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00016***	***0.00112***	0.07064	0.33138
2	P	B2	0.99985		1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00026***	***0.01283***	0.08968
3	P	B3	0.99752	1.00000		1.00000	0.99999	1.00000	1.00000	1.00000	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00021***	***0.00781***	0.05923
4	P	B4	1.00000	1.00000	1.00000		1.00000	1.00000	1.00000	1.00000	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00035***	***0.02072***	0.13237
5	P	B5	1.00000	1.00000	0.99999	1.00000		1.00000	1.00000	1.00000	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00049***	***0.03169***	0.18459
6	P	B6	0.99985	1.00000	1.00000	1.00000	1.00000		1.00000	1.00000	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00026***	***0.01283***	0.08968
7	P	B7	0.99931	1.00000	1.00000	1.00000	1.00000	1.00000		1.00000	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00023***	***0.01003***	0.07312
8	P	B8	0.99980	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000		***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00026***	***0.01230***	0.08672
9	R	B1	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***		0.10959	***0.00003***	***0.00003***	***0.00003***	***0.00003***	***0.00003***	***0.00003***
10	R	B2	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	0.10959		0.08019	***0.00003***	***0.00003***	***0.00003***	***0.00003***	***0.00003***
11	R	B3	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00003***	0.08019		0.11639	***0.00003***	***0.00003***	***0.00003***	***0.00003***
12	R	B4	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00003***	***0.00003***	0.11639		***0.00003***	***0.00003***	***0.00003***	***0.00003***
13	R	B5	***0.00016***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00003***	***0.00003***	***0.00003***	***0.00003***		0.83396	***0.00246***	***0.00004***
14	R	B6	***0.00112***	***0.00026***	***0.00021***	***0.00035***	***0.00049***	***0.00026***	***0.00023***	***0.00026***	***0.00003***	***0.00003***	***0.00003***	***0.00003***	0.83396		0.66341	0.05759
15	R	B7	0.07064	***0.01283***	***0.00781***	***0.02072***	***0.03169***	***0.01283***	***0.01003***	***0.01230***	***0.00003***	***0.00003***	***0.00003***	***0.00003***	***0.00246***	0.66341		0.99913
16	R	B8	0.33138	0.08968	0.05923	0.13237	0.18459	0.08968	0.07312	0.08672	***0.00003***	***0.00003***	***0.00003***	***0.00003***	***0.00004***	0.05759	0.99913	

Appendix D2

Post Hoc Table for Recall Success Immediate and Delayed English Prime Retention (Experiment 2)

	Condition	Test	1	2	3	4
			0.42	0.35	0.80	0.77
1	P	EPRI		***0.047524***	***0.007523***	***0.015126***
2	P	EPRD	***0.047524***		***0.001626***	***0.003249***
3	R	EPRI	***0.007523***	***0.001626***		0.583046
4	R	EPRD	***0.015126***	***0.003249***	0.583046	

Appendix D3

Post Hoc Table for Recall Success Immediate and Delayed Braille Prime Retention (Experiment 2)

	Condition	Test	1	2	3	4
			0.49	0.36	0.79	0.75
1	P	BPRI		***0.049734***	***0.030868***	0.074570
2	P	BPRD	***0.049734***		***0.001476***	***0.003952***
3	R	BPRI	***0.030868***	***0.001476***		0.809538
4	R	BPRD	0.074570	***0.003952***	0.809538	

Appendix D4

Post Hoc Table for Study Time Acquisition (Experiment 2)

Condition		Block	1 1829.6	2 1369.8	3 1294.1	4 1208.8	5 1112.7	6 1043.3	7 989.53	8 971.00	9 5211.0	10 3912.7	11 3179.2	12 2688.0	13 2183.5	14 1846.3	15 1682.7	16 1371.8
1	P	B1		0.93075	0.79801	0.56729	0.30371	0.16573	0.09536	0.07759	***0.00015***	***0.00015***	***0.00787***	0.39946	0.99938	1.00000	1.00000	0.98973
2	P	B2	0.93075		1.00000	1.00000	0.99984	0.99741	0.98725	0.97986	***0.00015***	***0.00015***	***0.00018***	***0.01080***	0.49341	0.98493	0.99986	1.00000
3	P	B3	0.79801	1.00000		1.00000	1.00000	0.99989	0.99882	0.99769	***0.00015***	***0.00015***	***0.00016***	***0.00496***	0.33882	0.94562	0.99818	1.00000
4	P	B4	0.56729	1.00000	1.00000		1.00000	1.00000	0.99998	0.99994	***0.00015***	***0.00015***	***0.00015***	***0.00201***	0.20131	0.84759	0.98569	1.00000
5	P	B5	0.30371	0.99984	1.00000	1.00000		1.00000	1.00000	1.00000	***0.00015***	***0.00015***	***0.00015***	***0.00074***	0.10026	0.66833	0.93042	0.99999
6	P	B6	0.16573	0.99741	0.99989	1.00000	1.00000		1.00000	1.00000	***0.00015***	***0.00015***	***0.00015***	***0.00040***	0.05686	0.51668	0.84486	0.99974
7	P	B7	0.09536	0.98725	0.99882	0.99998	1.00000	1.00000		1.00000	***0.00015***	***0.00015***	***0.00015***	***0.00027***	***0.03540***	0.40257	0.75099	0.99848
8	P	B8	0.07759	0.97986	0.99769	0.99994	1.00000	1.00000	1.00000		***0.00015***	***0.00015***	***0.00015***	***0.00025***	***0.02989***	0.36566	0.71420	0.99742
9	R	B1	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***		***0.00010***	***0.00003***	***0.00003***	***0.00003***	***0.00003***	***0.00003***	***0.00003***
10	R	B2	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00010***		0.26601	***0.00034***	***0.00003***	***0.00003***	***0.00003***	***0.00003***
11	R	B3	***0.00787***	***0.00018***	***0.00016***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00003***	0.26601		0.88602	***0.01336***	***0.00007***	***0.00003***	***0.00003***
12	R	B4	0.39946	***0.01080***	***0.00496***	***0.00201***	***0.00074***	***0.00040***	***0.00027***	***0.00025***	***0.00003***	***0.00034***	0.88602		0.86278	0.09377	***0.01165***	***0.00008***
13	R	B5	0.99938	0.49341	0.33882	0.20131	0.10026	0.05686	***0.03540***	***0.02989***	***0.00003***	***0.00003***	***0.01336***	0.86278		0.99632	0.86948	0.12883
14	R	B6	1.00000	0.98493	0.94562	0.84759	0.66833	0.51668	0.40257	0.36566	***0.00003***	***0.00003***	***0.00007***	0.09377	0.99632		1.00000	0.91169
15	R	B7	1.00000	0.99986	0.99818	0.98569	0.93042	0.84486	0.75099	0.71420	***0.00003***	***0.00003***	***0.00003***	***0.01165***	0.86948	1.00000		0.99850
16	R	B8	0.98973	1.00000	1.00000	1.00000	0.99999	0.99974	0.99848	0.99742	***0.00003***	***0.00003***	***0.00003***	***0.00008***	0.12883	0.91169	0.99850	

Appendix D5

Post Hoc Table for Reaction Time Acquisition (Experiment 2)

Condition		Block	1 513.20	2 380.56	3 338.84	4 329.19	5 300.16	6 302.04	7 278.58	8 259.58	9 4884.5	10 6026.9	11 5655.7	12 4668.7	13 4142.8	14 3849.2	15 3102.3	16 3238.7
1	P	B1		1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	***0.00014***	***0.00014***	***0.00014***	***0.00014***	***0.00016***	***0.00025***	***0.00798***	***0.00391***
2	P	B2	1.00000		1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	***0.00014***	***0.00014***	***0.00014***	***0.00014***	***0.00015***	***0.00019***	***0.00399***	***0.00193***
3	P	B3	1.00000	1.00000		1.00000	1.00000	1.00000	1.00000	1.00000	***0.00014***	***0.00014***	***0.00014***	***0.00014***	***0.00015***	***0.00018***	***0.00320***	***0.00155***
4	P	B4	1.00000	1.00000	1.00000		1.00000	1.00000	1.00000	1.00000	***0.00014***	***0.00014***	***0.00014***	***0.00014***	***0.00015***	***0.00018***	***0.00304***	***0.00147***
5	P	B5	1.00000	1.00000	1.00000	1.00000		1.00000	1.00000	1.00000	***0.00014***	***0.00014***	***0.00014***	***0.00014***	***0.00015***	***0.00018***	***0.00261***	***0.00127***
6	P	B6	1.00000	1.00000	1.00000	1.00000	1.00000		1.00000	1.00000	***0.00014***	***0.00014***	***0.00014***	***0.00014***	***0.00015***	***0.00018***	***0.00263***	***0.00128***
7	P	B7	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000		1.00000	***0.00014***	***0.00014***	***0.00014***	***0.00014***	***0.00015***	***0.00017***	***0.00233***	***0.00113***
8	P	B8	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000		***0.00014***	***0.00014***	***0.00014***	***0.00014***	***0.00015***	***0.00017***	***0.00210***	***0.00103***
9	R	B1	***0.00014***	***0.00014***	***0.00014***	***0.00014***	***0.00014***	***0.00014***	***0.00014***	***0.00014***		0.43002	0.94047	1.00000	0.95700	0.61135	***0.00670***	***0.02106***
10	R	B2	***0.00014***	***0.00014***	***0.00014***	***0.00014***	***0.00014***	***0.00014***	***0.00014***	***0.00014***	0.43002		0.99998	0.15276	***0.00263***	***0.00015***	***0.00003***	***0.00003***
11	R	B3	***0.00014***	***0.00014***	***0.00014***	***0.00014***	***0.00014***	***0.00014***	***0.00014***	***0.00014***	0.94047	0.99998		0.69135	0.05691	***0.00540***	***0.00003***	***0.00004***
12	R	B4	***0.00014***	***0.00014***	***0.00014***	***0.00014***	***0.00014***	***0.00014***	***0.00014***	***0.00014***	1.00000	0.15276	0.69135		0.99867	0.90451	***0.03874***	0.09891
13	R	B5	***0.00016***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	***0.00015***	0.95700	***0.00263***	0.05691	0.99867		1.00000	0.60243	0.81268
14	R	B6	***0.00025***	***0.00019***	***0.00018***	***0.00018***	***0.00018***	***0.00018***	***0.00017***	***0.00017***	0.61135	***0.00015***	***0.00540***	0.90451	1.00000		0.95434	0.99321
15	R	B7	***0.00798***	***0.00399***	***0.00320***	***0.00304***	***0.00261***	***0.00263***	***0.00233***	***0.00210***	***0.00670***	***0.00003***	***0.00003***	***0.03874***	0.60243	0.95434		1.00000
16	R	B8	***0.00391***	***0.00193***	***0.00155***	***0.00147***	***0.00127***	***0.00128***	***0.00113***	***0.00103***	***0.02106***	***0.00003***	***0.00004***	0.09891	0.81268	0.99321	1.00000	

Appendix D6

Post Hoc Table for Heart Rate Variability Immediate and Delayed English Prime Retention (Experiment 2)

	Condition	Test	1	2	3	4
			2.65	2.42	1.25	1.20
1	P	EPRI		0.935937	***0.034885***	***0.028581***
2	P	EPRD	0.935937		0.099124	0.083278
3	R	EPRI	***0.034885***	0.099124		0.999632
4	R	EPRD	***0.028581***	0.083278	0.999632	

Appendix D7

Post Hoc Table for Heart Rate Variability Immediate and Delayed Braille Prime Retention (Experiment 2)

	Condition	Test	1	2	3	4
			2.74	2.55	1.51	1.52
1	P	BPRI		0.983687	0.083709	0.086631
2	P	BPRD	0.983687		0.175375	0.180644
3	R	BPRI	0.083709	0.175375		0.999999
4	R	BPRD	0.086631	0.180644	0.999999	

Appendix D8

Post Hoc Table for NASA TLX (Experiment 2)

	Condition	Test	1 9.17	2 32.33	3 33.08	4 33.67	5 31.67	6 30.17	7 25.92	8 28.00	9 20.83	10 25.92
1	P	NASA 1		***0.000160***	***0.000160***	***0.000160***	***0.000160***	***0.001015***	***0.015636***	***0.004110***	0.235499	***0.015636***
2	P	NASA 2	***0.000160***		1.000000	0.999976	1.000000	0.999970	0.905363	0.992240	0.252493	0.905363
3	P	NASA 3	***0.000160***	1.000000		1.000000	0.999960	0.999643	0.833809	0.976702	0.182547	0.833809
4	P	NASA 4	***0.000160***	0.999976	1.000000		0.999307	0.998456	0.763403	0.953701	0.139095	0.763403
5	P	NASA 5	***0.000160***	1.000000	0.999960	0.999307		0.999999	0.949441	0.997781	0.328045	0.949441
6	R	NASA 1	***0.001015***	0.999970	0.999643	0.998456	0.999999		0.869767	0.998653	***0.033112***	0.869767
7	R	NASA 2	***0.015636***	0.905363	0.833809	0.763403	0.949441	0.869767		0.999011	0.702804	1.000000
8	R	NASA 3	***0.004110***	0.992240	0.976702	0.953701	0.997781	0.998653	0.999011		0.230731	0.999011
9	R	NASA 4	0.235499	0.252493	0.182547	0.139095	0.328045	***0.033112***	0.702804	0.230731		0.702804
10	R	NASA 5	***0.015636***	0.905363	0.833809	0.763403	0.949441	0.869767	1.000000	0.999011	0.702804	

Appendix E1

Pearson Correlation for HRV and NASA TLX measures (Experiment 2)

		Acqu	EPRI	BPRI	EPRD	BPRD
Condition	**n**	r, p	r, p	r, p	r, p	r, p
Proactive	12	r = .287, p = .366	r = -.101, p =.755	r = -.304, p = .336	r = -.229, p = .457	r = -.375, p = .23
Retroactive	12	r = .107, p = .742	r = -.153, p = .635	r = .034, p = .916	r = -.213, p = .507	r = -.464, p = .129

Appendix E2

Pearson Correlation for HRV and RS measures (Experiment 2)

		Acqu	**EPRI**	**BPRI**	**EPRD**	**BPRD**
Condition	**n**	r, p	r, p	r, p	r, p	r, p
Proactive	12	r = .428, p = .165	r = -.160, p = .619	r = -.30, p = .344	r = .382, p = .22	r = .397, p = .201
Retroactive	12	r = -.055, p = .865	r = -.184, p = .567	r = .30, p = .473	r = .417, p = .178	r = .22, p = .491

Appendix F

Ethics Approval

DATE: 6/21/2010
FROM: Michelle McGinn, Chair
Research Ethics Board (REB)
TO: Jae Patterson, PEKN
Amanda Hart
FILE: 09-272 PATTERSON
Masters Thesis/Project
TITLE: Cognitive effects of retroactive and proactive augmented information in learning a novel motor skill

The Brock University Research Ethics Board has reviewed the above research proposal.

DECISION: Accepted as clarified

This project has received ethics clearance for the period of June 21, 2010 to August 31, 2010 subject to full REB ratification at the Research Ethics Board's next scheduled meeting. The clearance period may be extended upon request. The study may now proceed.

Please note that the Research Ethics Board (REB) requires that you adhere to the protocol as last reviewed and cleared by the REB. During the course of research no deviations from, or changes to, the protocol, recruitment, or consent form may be initiated without prior written clearance from the REB. The Board must provide clearance for any modifications before they can be implemented. If you wish to modify your research project, please refer to http://www.brocku.ca/research/policies-and-forms/forms to complete the appropriate form Revision or Modification to an Ongoing Application.

Adverse or unexpected events must be reported to the REB as soon as possible with an indication of how these events affect, in the view of the Principal Investigator, the safety of the participants and the continuation of the protocol.

If research participants are in the care of a health facility, at a school, or other institution or community organization, it is the responsibility of the Principal Investigator to ensure that the ethical guidelines and clearance of those facilities or institutions are obtained and filed with the REB prior to the initiation of any research protocols.

The Tri-Council Policy Statement requires that ongoing research be monitored. A Final Report is required for all projects upon completion of the project. Researchers with projects lasting more than one year are required to submit a Continuing Review Report annually. The Office of Research Services will contact you when this form Continuing Review/Final Report is required.